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NASA'S SPACE SCIENCE AND APPLICATIONS PROGRAM

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A Statement Presented to the
Committee on Aeronautical and Space Sciences
United States Senate
April 20, 1967

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Washington, D.C. 20546

PREFACE

THE MATERIAL in this booklet is a reprint of a portion of that which was prepared by NASA's Office of Space Science and Applications for presentation to the Congress of the United States in the course of the fiscal year 1968 authorization process. It is believed to be of such general usefulness that it is being made available in this form to a wider audience.

A large part of the text is directed toward some of the issues that have been raised by the congressional committees. There is a discussion of basic research, its value as a source of knowledge, techniques and skills that go into the development of technology, and practical applications. Also discussed is the importance to the strength, well being, and security of our Nation of a continuing level of effort in basic research, of which space research is an important and fruitful component.

In addition, appendixes are provided to permit delving deeper into specific aspects of the subject should the reader wish to do so. Several of the appendixes are devoted to a review of the efforts of the Office of Space Science and Applications in the past and a discussion of the potential for the future. In particular, attention is called to the last appendix, which lists some of the practical benefits stemming from, contributing to, or likely to come from, the research in NASA's Advanced Research and Technology, Manned Space Flight, Space Science and Applications, and Technology Utilization programs.

HOMER E. NEWELL,
Associate Administrator for
Space Science and Applications.

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THE NATIONAL SPACE SCIENCE AND APPLICATIONS PROGRAM

Introduction

I am pleased to have the privilege of addressing the Committee on Aeronautical and Space Sciences on the subject of our national space science and applications program. In this tenth year of the Space Age there is much to report both on progress and on opportunities for the future.

When we began our space program, we did so with a very limited capability. We mounted, therefore, a strong effort to develop the technical and operational capability needed to accomplish our objectives in space. At the same time, with the strong support of the Congress and the country, we were able to undertake a substantial program in both science and applications.

Now, after a decade of hard work, we have built up a substantial space capability. Reliable space vehicles are available ranging all the way from small sounding rockets to the Saturn I and Titan III class vehicles, with the still larger Saturn V imminent. Automated techniques of space exploration and application have matured while chalking up a long string of successes in Mariner, Ranger, Surveyor, Lunar Orbiter, Explorers, Geophysical and Solar Observatories, Tiros and Nimbus, Syncom, the Applications Technology Satellite, and many others. The capability of man to operate in space is emerging as Gemini winds up a brilliant series of flights, as the Apollo program proceeds, and as we start work on the Apollo Applications Program.

As a result of our hard-won gains, we can begin to devote a greater proportion of our space effort to practical applications and scientific and technological research. The future holds much promise of even greater returns on our investment than the remarkable output of the past.

In the first decade of the Space Age, we have also hammered out a better understanding of what space means to us, and how it can contribute in many ways to important national objectives. We have come to perceive the importance of challenging, broad, scientific and technological efforts to the technical health of the nation, and to appreciate the importance of the space effort in this respect. Many countries have come to equate preeminence in space with technical leadership on Earth. As a result, scientific and technological prestige derived from successes in space have a definite influence at the negotiating table, and on where other nations seek guidance and buy technological products, services, and training. One of the most important returns from an overall space capability is our ability to control our own destiny in space and in the Space Age, and to avoid a situation in which another country could restrict our use of space or our freedom of action in space. These points are developed at greater length in Appendix I.

Our rapidly developing capability has enabled us to achieve many successes in the past, and now affords us a wide range of choices of profitable missions to undertake in the future. I propose in Chapter I to discuss in broad perspective progress and opportunities in space science. In Chapter II I will discuss space applications. In Chapter III I will review the Fiscal Year 1968 budget request for the Space Science and Applications Program.

CHAPTER I. PROGRESS AND OPPORTUNITIES IN SPACE SCIENCE

Space science

The rocket, satellite, and space probe are powerful tools for scientific research. With them the investigator has been able to tackle many important and fundamental problems that could not be attacked effectively hitherto. With space techniques observations can now be made that are simply impossible at the surface of the Earth at the bottom of our obscuring and distorting atmosphere. As a consequence, space science has had a major impact on many of the major scientific disciplines, stimulating and enlarging their scope, and adding to the power of their assault on the frontiers of ignorance. We shall discuss this point at some length a little later.

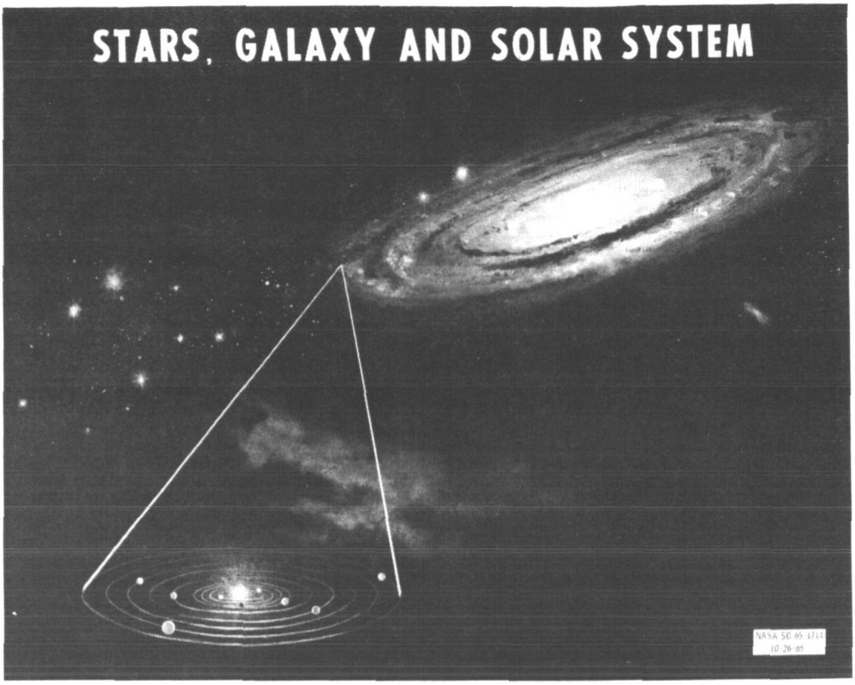

FIGURE 109

In broad perspective space science includes two major areas of research (fig. 109):

Exploration of the solar system.

Investigation of the universe.

The first category includes the scientific investigation of our Earth and its atmosphere, the Moon and planets, and the interplanetary medium. The nature and behavior of the Sun and its influence on the solar system, especially on the Earth, are of prime importance. With the availability of space techniques, we are no longer limited in direct observations to a single body of the solar system, but may now send our instruments and even men to explore and investigate other objects in the solar system. The possibility of comparing the properties of the planets in detail adds greatly to the power of investigation of our own planet. Potentially far-reaching in its philosophical implications, is the search for life on other planets.

The fundamental laws of the universe in which we live are the most important objects of scientific search. Space techniques furnish a most powerful means of probing the nature of the universe, by furnishing the opportunity to observe and measure from above the Earth's atmosphere in wavelengths that cannot penetrate to the ground. There is also the opportunity to perform experiments on the scale of the solar system using satellites and space probes to study relativity, to delve into the nature of gravitation, including a search for the existence of gravitational waves.

Historical perspective

Seizing upon the opportunities before us, in the very first months and years of the Space Age, this country undertook as diverse a program of space science, technology, and applications as its limited capability would permit. In the brief span since those years of early decision, all of the first generation missions undertaken in our national space flight program have been brought to flight stage; except for the Orbiting Astronomical Observatory (OAO) all have achieved successful flights, and we are on the verge of success with that project. It is significant that the OAO is in many respects the most difficult and most advanced of the scientific missions undertaken by this country.

Except for the extensive sounding rocket program, the record is set forth on the table of figure 110. Scientific successes recorded in the table include dozens of Explorers (atmosphere; magnetosphere; geodesy; space environment), Orbiting Solar Observatories (Sun), Orbiting Geophysical Observatories (multidisciplinary studies covering the atmosphere, magnetosphere, Sun, and space environment); many satellites launched for other countries in cooperative programs (atmosphere; ionosphere; Sun; space environment), the Ranger and Surveyor lunar missions (Moon), Pioneer deep space probes (space environment), and the Mariners to Venus and Mars (planets; space environment). As I mentioned in the introduction, a later paper will discuss the very successful and productive applications program.

Figure 111 lists the second round of missions undertaken in our space program since 1960. Many of these have also come to fruition. Eminently satisfying has been the brilliant Gemini program, in which many scientific experiments have been carried out (Earth and weather photography; space environment; astronomy; bioscience). The second generation missions include advanced Explorers, such as the Interplanetary Monitoring Platform, called IMP, (space environment), and the GEOS and Pageos geodetic satellites (Earth structure; mapping). Of the new international cooperative satellites, the second Canadian Alouette (ionosphere; cosmic rays) and the Italian San Marco (atmosphere) launches were highly successful. New and improved Pioneers even now are orbiting the Sun, sending back important data on solar activity and the interplanetary medium. Spectacular pictures of the Moon from our two Lunar Orbiters have appeared on front pages of newspapers around the world.

The year 1966 saw a spectacular assault on the secrets of the Moon with Surveyor and Lunar Orbiter automated spacecraft. These achievements are beautifully symbolized by Lunar Orbiter's memorable photograph of the Earth dominating the sky above the lunar horizon (fig. 112). While missions such as

NASA MISSIONS STARTED BEFORE 1 JANUARY 1961

MISSION	DATE OF FIRST SUCCESS	TOTAL SUCCESSES TO 31 JAN 1967
VANGUARD*	17 MAR 1958	2
EXPLORER*	1 FEB 1958	25
PIONEER**	3 MAR 1959	2
ORBITING SOLAR OBSERVATORY	7 MAR 1962	2
ORBITING ASTRONOMICAL OBSERVATORY	---	--
ORBITING GEOPHYSICAL OBSERVATORY	7 JUN 1966	1
INTERNATIONAL	26 APR 1962	2
RANGER	28 JUL 1964	3
SURVEYOR	30 MAY 1966	1
MARINER	27 AUG 1962	2
ECHO	12 AUG 1960	2
RELAY	13 DEC 1962	2
TIROS	1 APR 1960	10
NIMBUS	28 AUG 1964	2
MERCURY (MANNED)	5 MAY 1961	6
LITTLE JOE	4 OCT 1959	7
SATURN	27 OCT 1961	13
CENTAUR***	27 NOV 1963	7
DELTA	12 AUG 1960	41
SCOUT****	1 JUL 1960	39

* PART OF IGY BEFORE CREATION OF NASA
** STARTED BY USAF
*** STARTED BY ADVANCED RESEARCH PROJECT AGENCY (ARPA)
**** INCLUDES LAUNCHES FOR DOD AND AEC

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FIGURE 110

NASA MISSIONS STARTED AFTER 1 JANUARY 1961

MISSION	DATE OF FIRST SUCCESS	TOTAL SUCCESSES TO 31 JAN 1967
ADVANCED EXPLORER	26 NOV 1963	3
NEW PIONEER	16 DEC 1965	2
NEW INTERNATIONAL	27 MAR 1964	3
LUNAR ORBITER	10 AUG 1965	2
APPLICATIONS TECHNOLOGY SATELLITE	6 DEC 1966	1
SYNCOM	26 JUL 1963	2
GEODETIC	6 NOV 1965	2
ESSA *	3 FEB 1966	4
BIOSATELLITE	---	--
PEGASUS	16 FEB 1965	3
FIRE	14 APR 1964	2
REENTRY	18 AUG 1964	2
SERT	20 JUL 1964	1
RAM	---	--
GEMINI (MANNED)	23 MAR 1965	10
APOLLO (MANNED)	---	--
LITTLE JOE II	28 AUG 1963	4
NON-NASA MISSIONS		
TELSTAR	10 JUL 1962	2
INTELSAT	6 APR 1965	3 (Vehicle Only)

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* BUILT AND LAUNCHED BY NASA FOR ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

FIGURE 111

SPACE SCIENCE AND APPLICATIONS

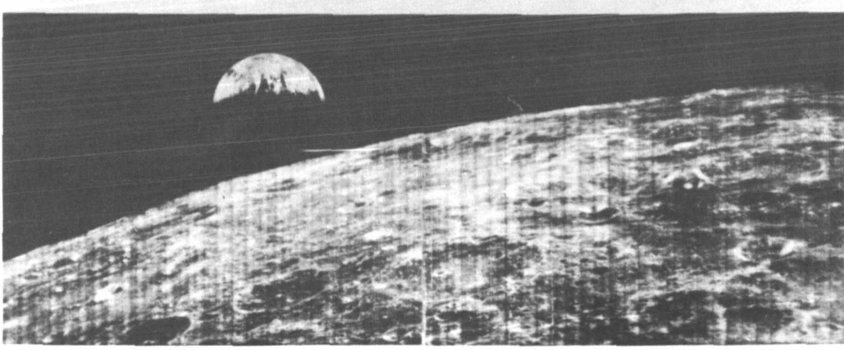


FIGURE 112

these were capturing most of the headlines as well as the public imagination, they were also being matched by equally significant progress in other areas, including pertinent and supporting ground-based research.

The accomplishments of the past two years have clearly established the capability of this nation to carry out successfully complicated automated science and applications missions in space. We have made substantial progress in the development of a manned capability for similar purposes. A strong base has been laid for continuing success in whatever space missions we may undertake.

By way of comparison, the Russians continue to publish at an increasing rate in the area of space science, as is shown in the analysis of Appendix II, which was compiled by NASA's Goddard Institute for Space Studies. Nevertheless, the United States has maintained a lead through 1965. It will, however, be important to watch for what effects the recent increase in automated exploration of the Moon and cislunar space will have on both the absolute and relative numbers of Soviet space science publications.

Time for decision

Many of our first and second generation projects have been completed or are nearing completion. The space research effort has been abundantly fruitful in answering first and second generation questions about our space environment, and in turning up a whole new generation of fundamental and important questions, and potentially fruitful practical applications. To answer these new questions and to continue advancing in this important field, it is time to select new missions to replace old ones.

The importance of this point may be seen from figure 113. This chart shows the flight activity in the Space Science and Applications Program since 1960. Flights to which we have committed ourselves are shown as launched or scheduled. They are subdivided into major missions requiring Agena, Centaur, or Saturn launch vehicles, and small spacecraft requiring the Scout or Delta launch vehicles. The number of scheduled missions is seen to decrease rapidly to zero in the early 1970's. There is both the opportunity to introduce new missions into the science

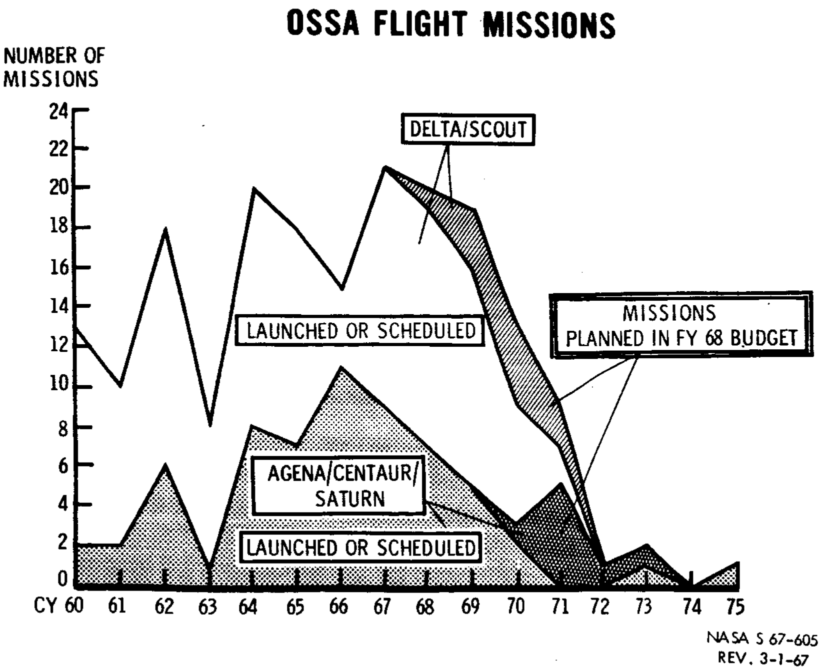


FIGURE 113

and application program, and the necessity to do so, to tackle the new problems we now have before us, to keep in trim the magnificent team that we have put together, and to maintain our forward thrust. The Fiscal Year 1968 budget includes funds to conduct work on additional missions as indicated in the chart. These missions, which include Voyager, will be discussed by Mr. Edgar Cortright in a later paper.

The proposed new work is selected from a wide range of choices now open to us, because of our growing space capability. When the Space Age began, we as a nation were constrained to responding to the challenge represented by Sputnik I with whatever we could do in space. A decade later the situation is entirely different. The number of space goals that are now within reach is so great that we can set aside the question of what can we do and turn our attention to what should we do.

The importance and value of options now open to us in science are discussed in the next section.

The impact of space research on science

The impact of space research on science has already been appreciable, international in scope. With the Space Age, a new phrase came into use; *space science*, meaning basic scientific research in or directly related to space. Space science is, however, not a new science or even a new scientific discipline. Rather, it is the extension of numerous classical disciplines by the application of space techniques to the solution of important scientific problems. Therein lies the vitality of space science. that it contributes in powerful ways to the broadening and strengthening of science right here on Earth.

Let us illustrate the above point by discussing several specific examples. It should suffice to consider four major disciplines: geoscience, physics, astronomy, and bioscience. All of these disciplines are thoroughly involved in the pursuit of our objectives of exploring the solar system and investigating the universe.

Geoscience

The impact of space techniques upon the geosciences, i.e., the study of our Earth, has been truly dramatic. Through the space approach, geoscience has been strengthened and extended in four significant ways:

By providing powerful new tools.
By opening up new areas of geoscience.
By extending geoscience to other planets.
By drawing geoscience, astronomy, and physics closer together.

Let us discuss these four points in order.

New tools for geoscience

First, sounding rockets and satellites have furnished a powerful new line of attack on old problems. One of these problems is the investigation of the Earth's upper atmosphere beyond the reach of aircraft and balloons. Those familiar with this field are keenly aware of the struggles, starting in the early 1900's and extending over nearly half a century, to glean information from various indirect sources about the properties and behavior of the high atmosphere. Some remarkably good detective work was done, but progress was slow and very uncertain. There were simply too many parameters not subject to direct measurement to permit achieving unambiguous answers.

With the sounding rocket, and later the artificial Earth satellite, the pace of definitive observation and measurement increased by orders of magnitude. The pressure and density of the atmosphere were determined to heights of thousands of miles. Molecules and ions in the upper atmosphere were identified. It was found that in the middle ionosphere ionized oxygen atoms appear (fig. 114) instead of the neutral oxygen molecules found at sea level. Still higher is a region dominated by helium, and even farther out a region of predominantly hydrogen. Atmospheric motions, the aurora, and other high altitude phenomena came under the revealing scrutiny of spaceborne instrumentation.

It was possible to observe the solar spectrum at various altitudes, thereby determining where the different solar wavelengths are absorbed in the atmosphere. These data are critical to understanding the influence of the Sun upon our atmospheric environment.

It is the word "environment" that is the key to the practical importance of much of space science. Through the results of space research we understand better the nature and behavior of our environment, and its influence upon our

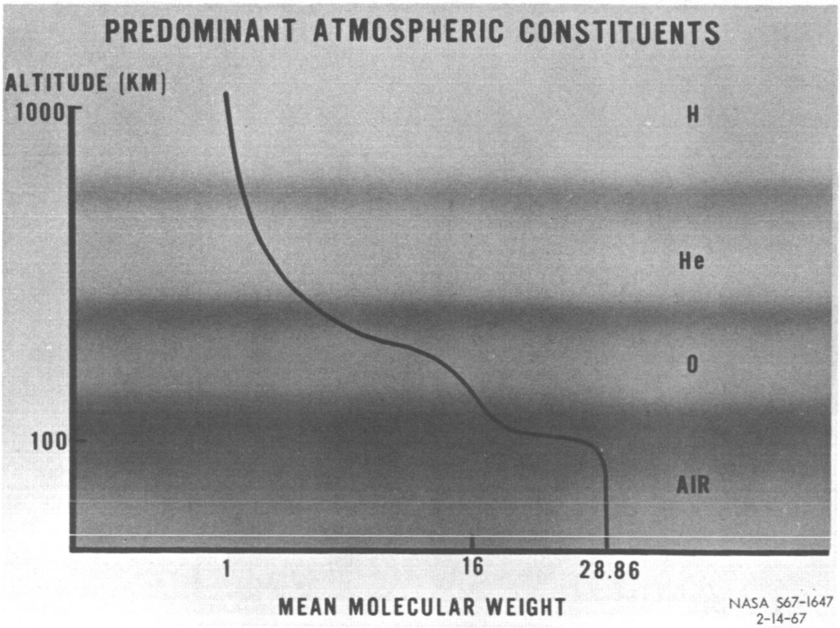


FIGURE 114

lives. With such knowledge we are better able to cope with the problems of living in the Earth environment and of using the Earth and space environment to full advantage.

For example, understanding the lower atmosphere and its behavior is especially significant at this time when we are wrestling with the possibilities of actually modifying weather to serve practical needs, such as enhancing water supplies, decreasing lightning hazard, protecting crops from storm damage, and perhaps in the more distant future even taming the hurricane and the tornado. The atmosphere affects the design of airplanes, missiles, and satellites; and has a major influence on various forms of radio communication, including the guidance and control of our own rockets, and the detection and interception of enemy missiles.

The problem of atmospheric pollution, which affects us all, needs thoughtful and searching attention. Urban smog is no longer an occasional phenomenon, but is a threat to most large cities. The frequency of smog in the Los Angeles area is well known (fig. 115). Smogs of London, New York City, and Pittsburgh have been highly distressing, even fatal to some. One solution to this problem would be to stop burning fuels for home and industry, stop driving automobiles, and forego those activities that inject contaminants into the atmosphere, and to understand thoroughly the behavior of our atmosphere, and what our activities do to it, so that we may devise ways of living and working that leave our environment unharmed.

The above are obvious examples of the direct practical application of knowledge about our environment. But there are hidden importances that may escape attention until too late if we do not continue to press for a clear perception of man's environment and his role in it. Let me cite two examples.

The amount of carbon dioxide in the atmosphere has increased eight percent in the last 60 or 70 years. Over this period there has been a great growth in industrial activity and in the use of the internal combustion engine. Since carbon dioxide in the atmosphere absorbs heat radiated from the ground, increasing carbon dioxide content implies a gradually increasing temperature at the Earth's surface. It would take only a few degrees rise in the average

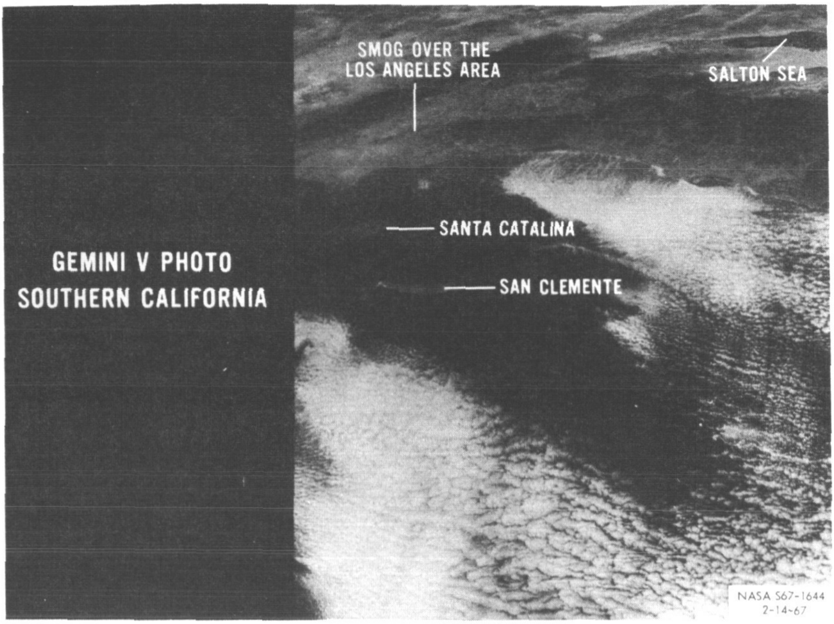


FIGURE 115

temperature of the atmosphere to cause profound changes in climate, the melting of the polar ice caps, with sufficient changes in sea level to inundate low-lying land masses such as Florida. It has been suggested that the melting of Arctic and Antarctic ice would soon lead to an increase in the Earth's cloud cover followed by increased and widespread snowfall. This could be the start of the next great ice age.

Even more subtle is the influence we may be exerting on the ultimate sources of life-giving oxygen in our atmosphere. It was once a favorite theme of science teachers to point out that, although the atmosphere is not a chemical compound, nevertheless, the proportions of the major constituents like nitrogen and oxygen are absolutely unchanging. This point of view, however, is an illusion fostered by the vastness of the atmosphere and the extreme slowness of changes. But, changes do occur, as illustrated by the previous example of the carbon dioxide content of the air.

The fact is that oxygen is constantly being removed from the air, for example, by oxidation of the rocks of the Earth's crust. This loss is offset by the escape to the atmosphere of oxygen from the oceans where oxygen is continually being released by photosynthesis in marine plants. There are indications that marine life is absorbing and being affected by pesticides and herbicides that are being washed into the oceans. Since there is no known buffer or stabilizer for the equilibrium of oxygen in the photosynthesis-atmosphere cycle, the amount of oxygen in the atmosphere may be expected to decrease as the balance of the plant and animal ecology of the oceans is drastically disturbed. Because there are now about a half million tons of oxygen per inhabitant on Earth, and because any changes will appear to be quite slow, harmful long-term effects will not be easily perceptible in the critical early stages. The concern is that by the time significant changes are evident, it may already be too late to remedy the situation. The consequences of ignorance are potentially so drastic that the investment in knowledge becomes a must.

The story of our atmosphere is as fascinating as it is important. In these few paragraphs I have no more than touched upon the subject. A more detailed account is given in Appendix III: "The Story of the Earth's Atmosphere,"

written by Dr. Robert Fellows, Planetary Atmospheres Program Chief, Office of Space Science and Applications, NASA Headquarters.

The significance of the atmosphere in our lives is clear. The interplanetary medium and the Sun have a related importance. The Sun literally controls the state and behavior of the Earth's atmosphere (fig. 116) by transmitting prodigious quantities of energy to Earth through the interplanetary medium. Thus, from the practical importance of scientific research on our *local* environment, we are inevitably led to the importance of investigating our *space* environment.

Because of its importance in assessing our investment in space research, I have discussed briefly the practical importance of thoroughly understanding our environment. Let us return now to the original point we were making, that space techniques have enabled geoscience to take a more effective approach to the solution of some long-standing problems. The investigation of the Earth's atmosphere, a significant part of our local environment, was one of those problems.

Land and water, too, are important parts of our environment that space techniques are helping us to investigate. By observing the effect of the Earth's gravitational field on the orbits of artificial Earth satellites, it has been possible to analyze the gravitational field to a high degree of accuracy, to deduce the strength of the Earth's upper mantle, to describe in considerable detail the true shape of the Earth, and hence to improve our mapping capabilities. Earth photography, like that from the various Gemini missions, adds new power and perspective in studying geography (fig. 117), geology (fig. 118), hydrology (fig. 119), glaciology (fig. 120), oceanography (fig. 121), forestry (fig. 122), and agriculture (fig. 123). The potential of these areas of science for practical returns is tremendous.

New areas of geoscience

The second impact of space research upon geoscience is in the opening up of new, unsuspected areas in the discipline. Investigation of the Earth's magnetosphere is an entirely new aspect of geoscience, which began with James Van

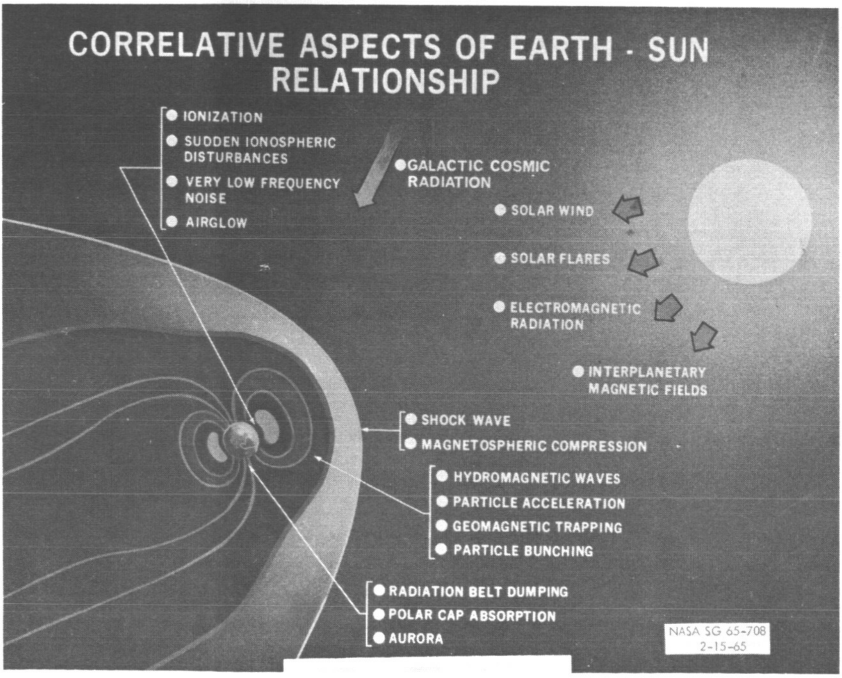


FIGURE 116

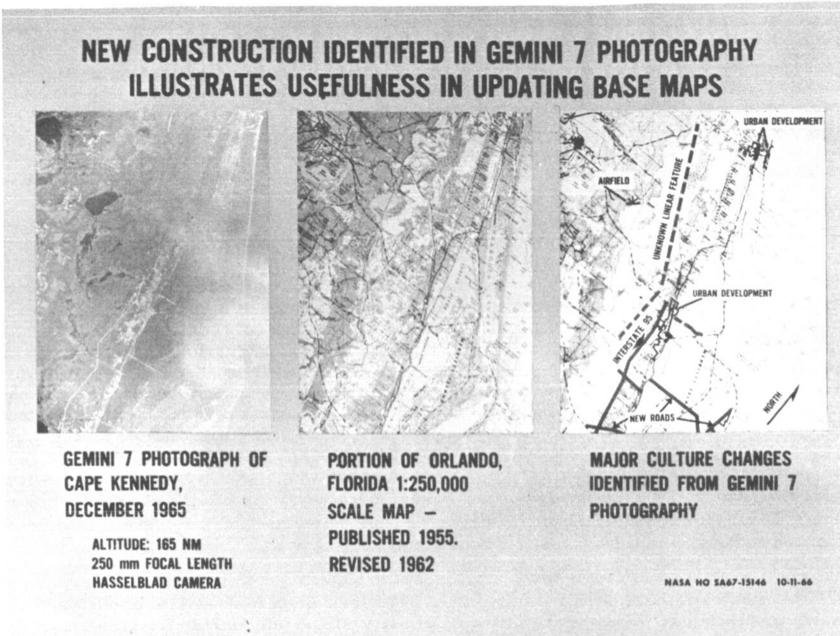


FIGURE 117

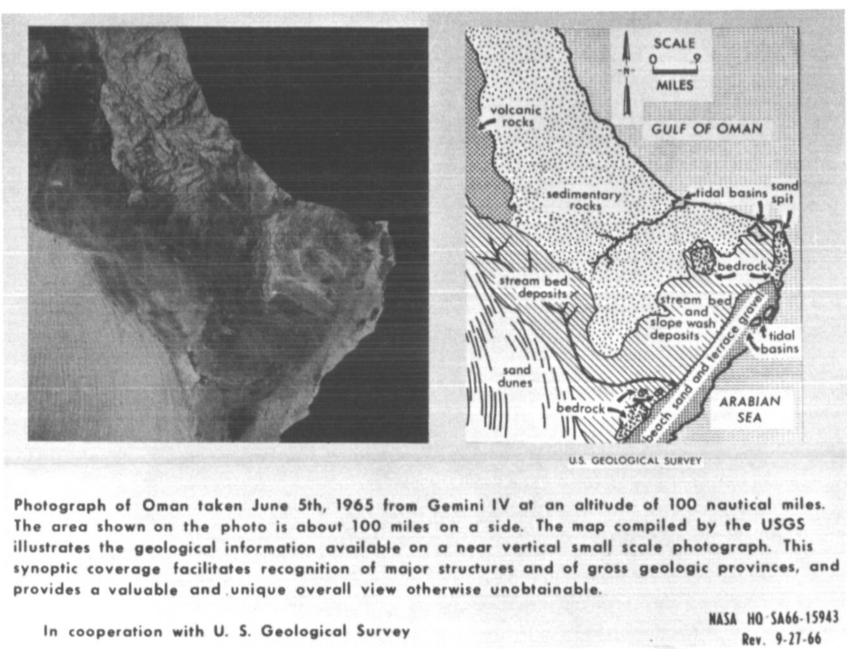


FIGURE 118

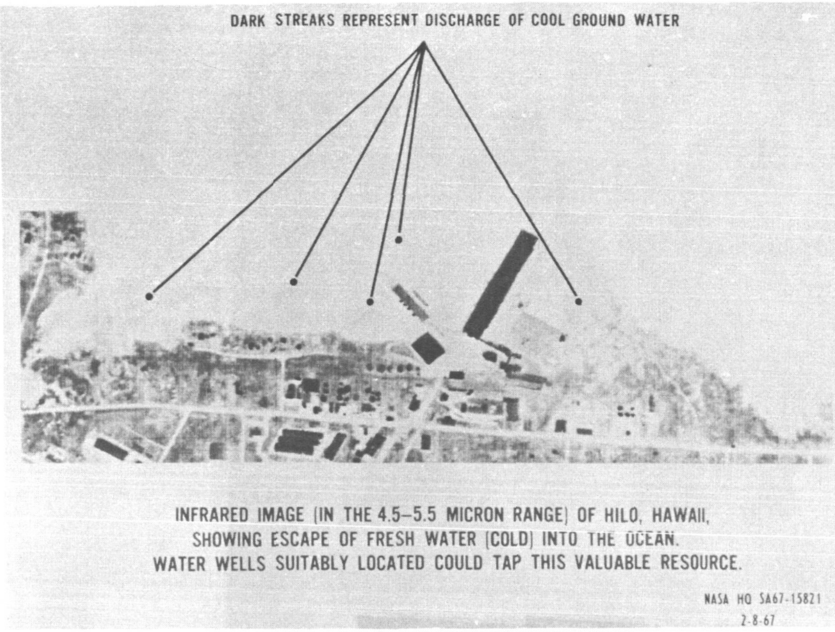


FIGURE 119

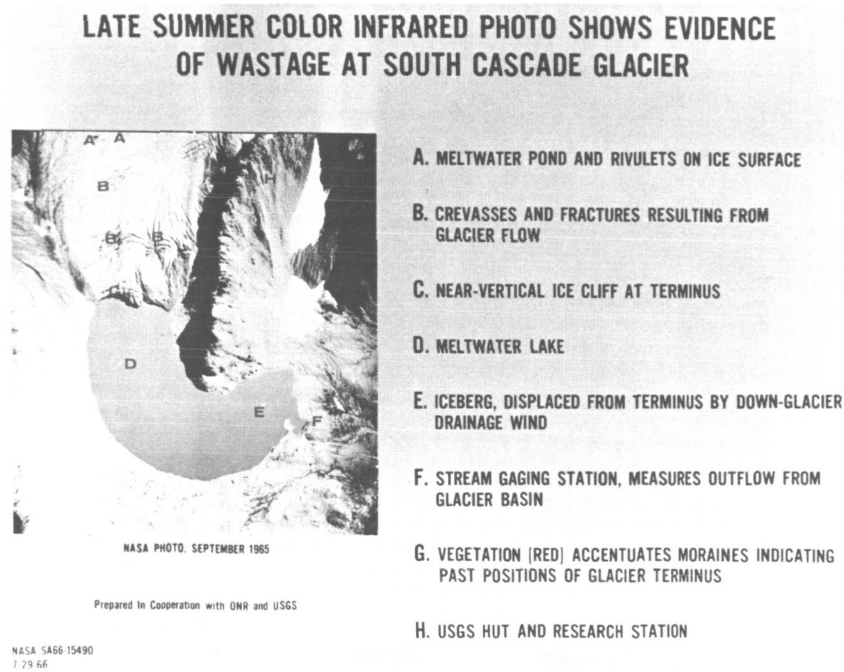


FIGURE 120

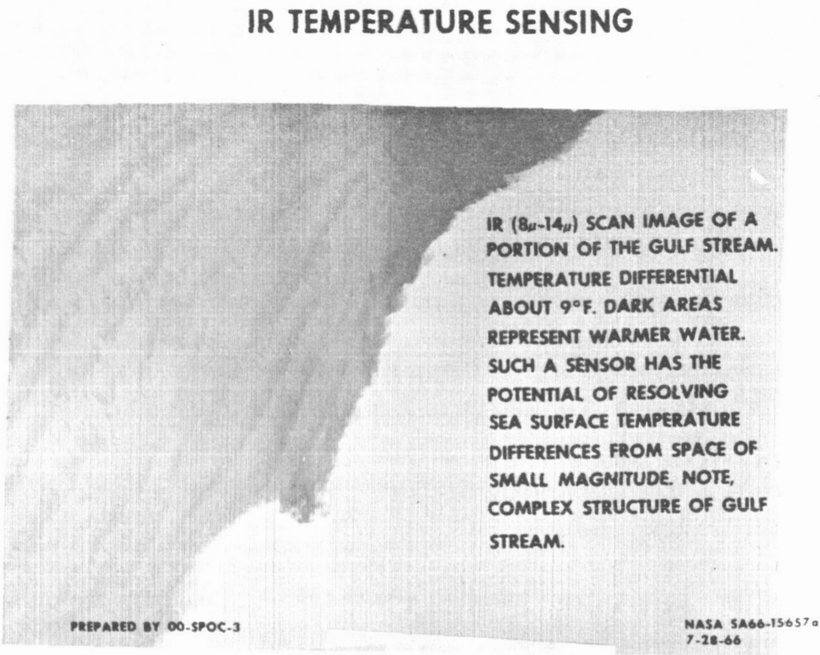


FIGURE 121

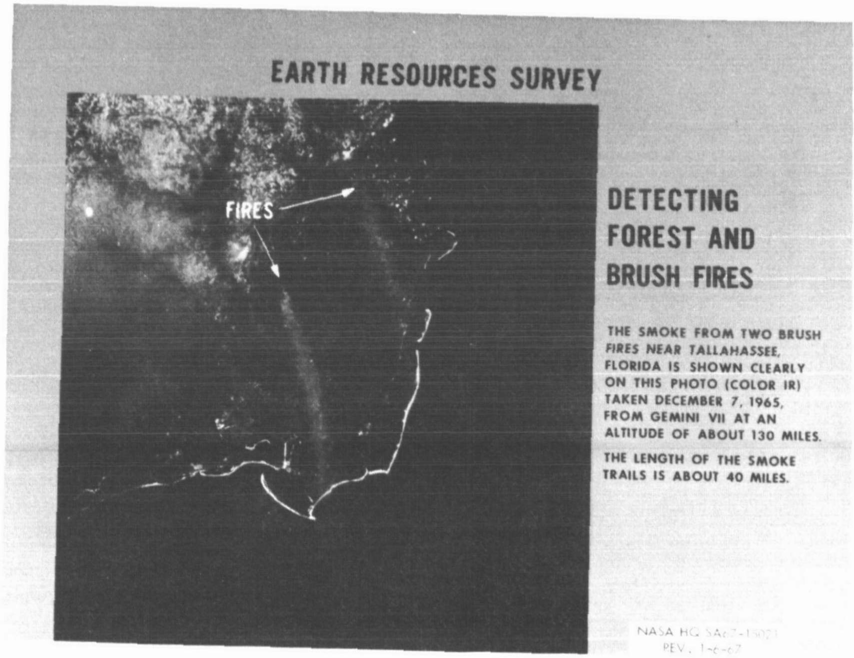


FIGURE 122

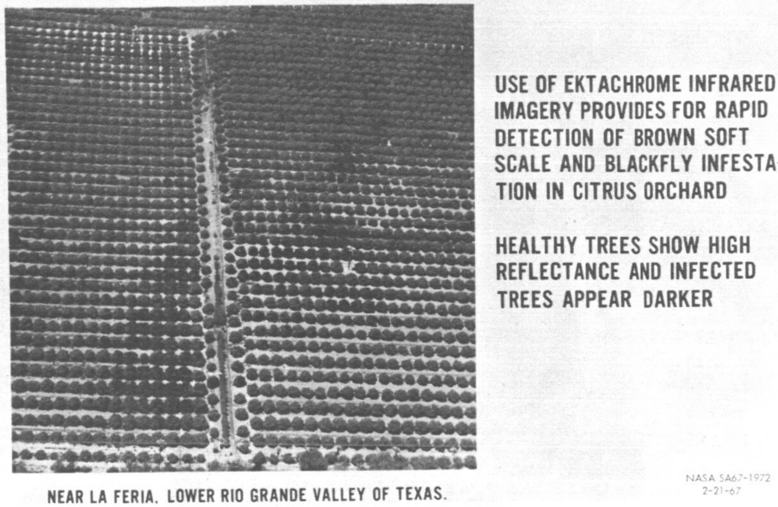


FIGURE 123

Allen's discovery of the radiation belts. Indeed, the magnetosphere is new, coined to designate that region of the interplanetary medium over which the Earth's magnetic field has a dominating influence.

Occupying a cavity carved out of the solar wind by the Earth's magnetic field, as shown in figure 124, the magnetosphere is enveloped on the sunward side by an immense shock wave that sweeps around the Earth in much the same way that an aerodynamic shock wave accompanies a supersonic aircraft. The magnetopause, or boundary of the magnetosphere, lies behind the shock wave, while within the magnetosphere itself are the trapped radiations that comprise the Van Allen Belts. These radiation belts are a sort of no-man's land where radiation intensities are too high to permit any prolonged manned operations.

While the magnetosphere reaches a distance toward the Sun of 10 or 15 Earth radii from the Earth, in the anti-solar direction the Earth's field lines are swept out by the solar wind to great distances. The total extent of this magnetospheric tail, which some have likened to that of a comet, is still not known, although it clearly reaches well beyond the distance of the Moon's orbit (fig. 125). Explorer XXXIII has provided data on the magnetospheric tail from a distance of 75,000 miles beyond the Moon's orbit. Moreover, instruments in the deep space probe Pioneer VII have detected some effects of the Earth on the solar wind at more than four million miles beyond the Earth.

The study of the magnetosphere is inextricably interwoven with investigations of the aurora, magnetic storms, and magnetic fluctuations, communications disturbances, and weather anomalies on the one hand, and of the interplanetary medium and solar activity on the other. To understand the important relations among these various phenomena, we are now investigating the dynamics of the magnetosphere. With such studies we expect to learn about the detailed mechanisms by which the Sun exerts its control on the Earth's atmosphere.

A discussion of the Earth's magnetosphere is given in Appendix IV: "The Solar Wind and the Earth's Magnetosphere," by Dr. George Pieper, Assistant Director for Space Sciences, Goddard Space Flight Center.

The existence of an Earth's magnetosphere immediately suggests the possibility of other planetary magnetospheres, the study of which may shed still further light on solar-planetary relationships. The instruments on Mariner II and Mariner IV, however, have shown that Venus and Mars have weak magnetic fields, if any, and hence do not have pronounced magnetospheres like that of Earth. On the other hand, radio wavelength emissions from the planet Jupiter

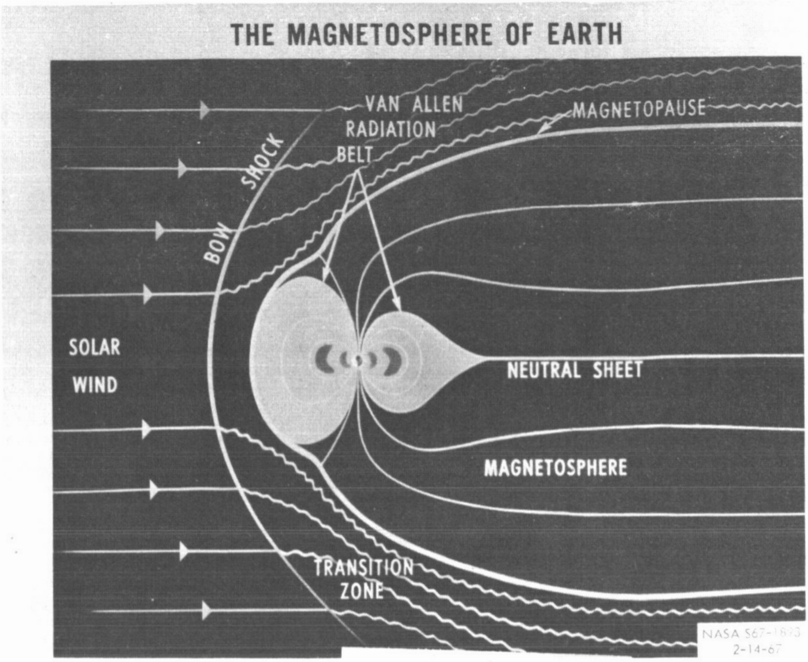


FIGURE 124

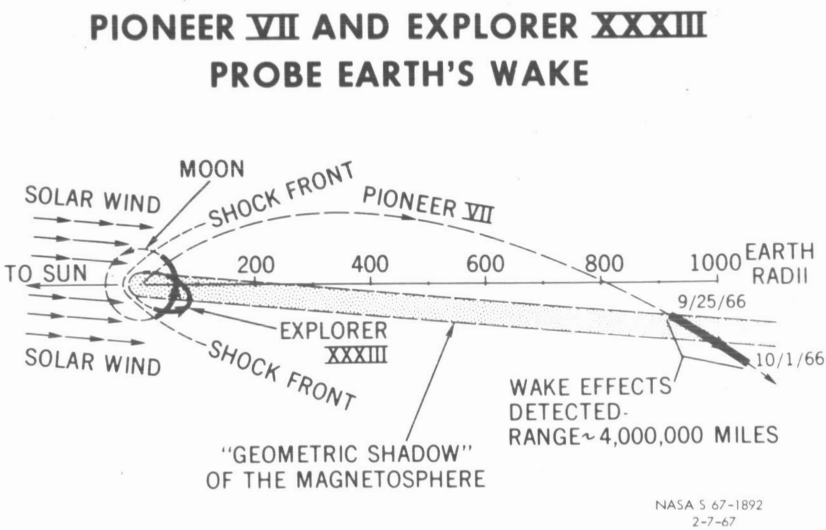


FIGURE 125

indicate that Jupiter has an extensive magnetosphere, reaching to millions of miles from the planet itself (fig. 126). It is clear, from the intensity of these radio emissions, that the Jupiter radiation belts are at least a thousand times more intense than those of the Earth.

It may even be correct to think of our Earth as revolving within a solar magnetosphere. Perhaps interplanetary space divides into two regions: a solar magnetosphere region enveloping the nearer planets, and the remote reaches of the solar system where galactic space conditions prevail. A challenging problem of space research is to find and probe the boundary between these two regions and to enter and study the true interstellar medium.

Geoscience and the other planets

The third profound impact that space activities are having on geoscience involves the planets. The domain of geoscience has grown to include many bodies of the solar system. No longer must the geoscientist be content with only one sample of the solar system, namely, the Earth. Now automated instruments, and later men, can go to the Moon and planets (fig. 127), to ask of those other bodies the same questions that the scientist has long been asking about the Earth. The theories, instruments, and skills needed and developed to study the Earth can now be applied to investigating the Moon and planets at firsthand (fig. 128). Conversely, improvements in instrumentation achieved to further the study of the planets directly benefit the investigation of the Earth.

The need for lighter, compact, reliable, and sensitive scientific instrumentation and advanced techniques for observation and analysis from spacecraft and on the lunar surface has resulted in new designs and miniaturized instruments, such as mass spectrometers, gas chromatographs, differential thermal analyzers, diffractometers, spectrometers, radiometers, radar transmitters and receivers, gravimeters, seismometers, and magnetometers. Many, if not all, of these will find application to Earth problems, including the search for new sources. As an example, the small X-ray diffractometer developed for use on a Surveyor space-

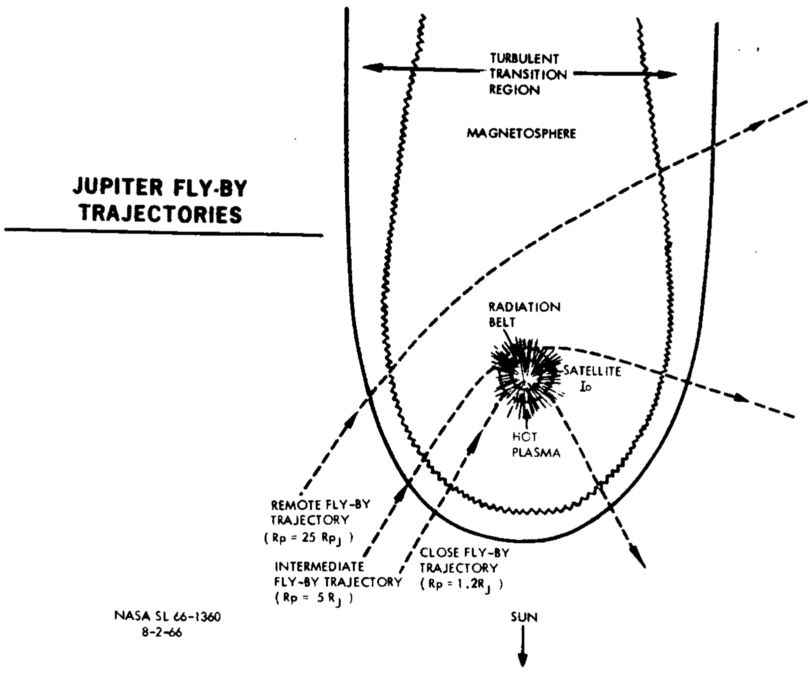


FIGURE 126

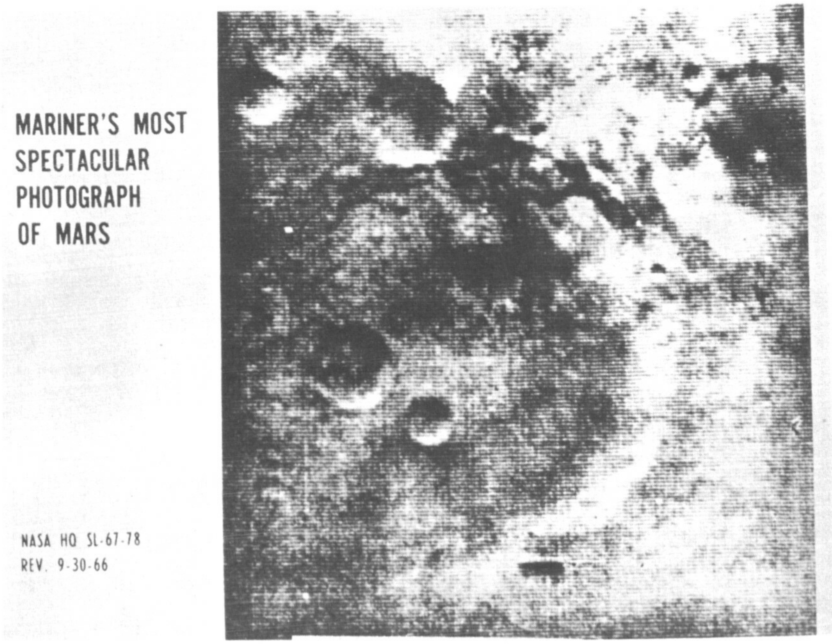


FIGURE 127

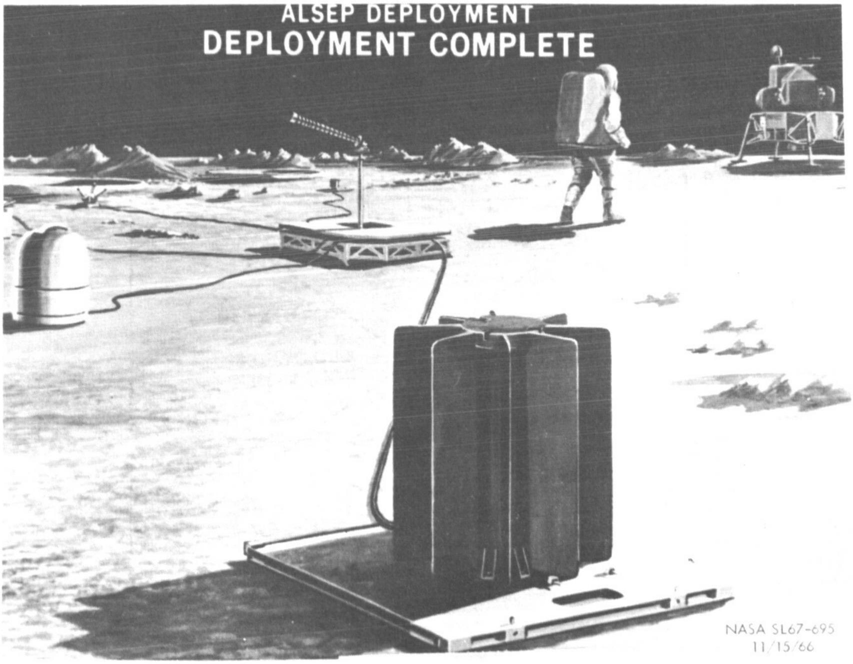


FIGURE 128

craft to make mineralogic determinations on the lunar surface appears to be more effective than some much larger laboratory instruments.

Comparative studies of the planets and their atmospheres, ionospheres, and magnetospheres, promise increased understanding of our own planet. The investigation of solar-terrestrial relationships can now become the study of solar-planetary relationships. If it is true, as has been suggested, that the composition of Jupiter is essentially that of the primordial material from which the solar system formed, the study of Jupiter, fascinating and important in itself, should also assist in probing into the origins of the solar system and our Earth.

The important scientific problems that are involved in the study of the planets, and their bearing on our understanding of the Earth, are developed at length in Appendix V: "The Planets," by Dr. Robert Jastrow, Director, Institute for Space Studies, Goddard Space Flight Center, and Dr. William Brunk, Program Chief, Planetary Astronomy, Office of Space Science and Applications, NASA Headquarters.

Partnership among geoscience, astronomy and physics

Finally, the fourth impact of space research on geoscience is the drawing together of physics, astronomy, and the geosciences in the study of solar-terrestrial relationships, and in the comparative study of the Earth, Moon, and planets.

The investigation of the Moon and planets has long been in the domain of astronomy. Now, as instruments, and later man, reach these other bodies of the solar system, the investigation of them extends into the geosciences.

Modern Earth-based telescopes have made it possible to view the Moon in great detail. However, the best photographic resolutions have been on the order of a half mile, and visual resolutions only a little better (fig. 129). When Ranger took its pictures of the Moon, figuratively speaking it put into the hands of the astronomer a telescope a thousand times as powerful as any hitherto available. Objects less than two feet in size could be resolved in the best of the Ranger and Lunar Orbiter pictures (fig. 130). When Surveyor landed, it provided the astronomer with still further improvement in resolu-

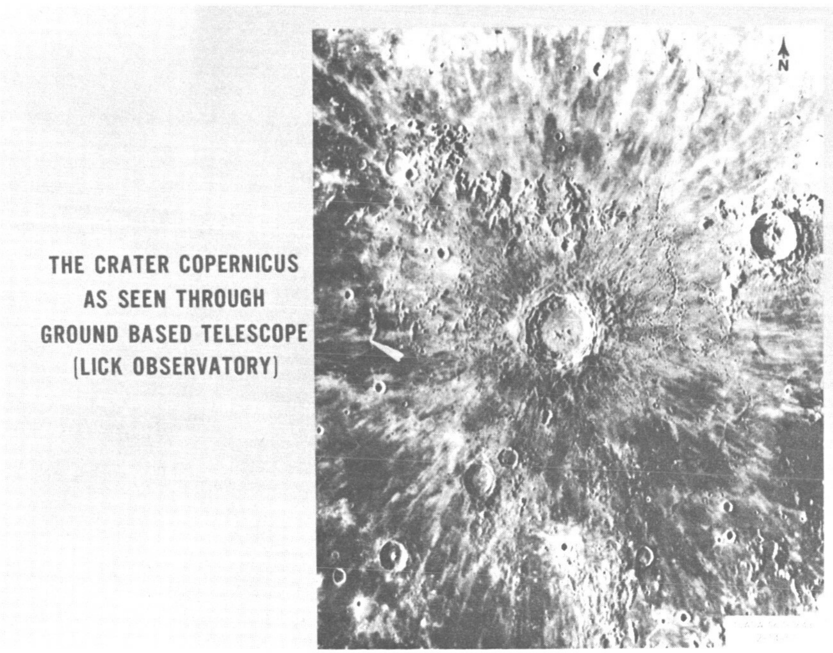


FIGURE 129

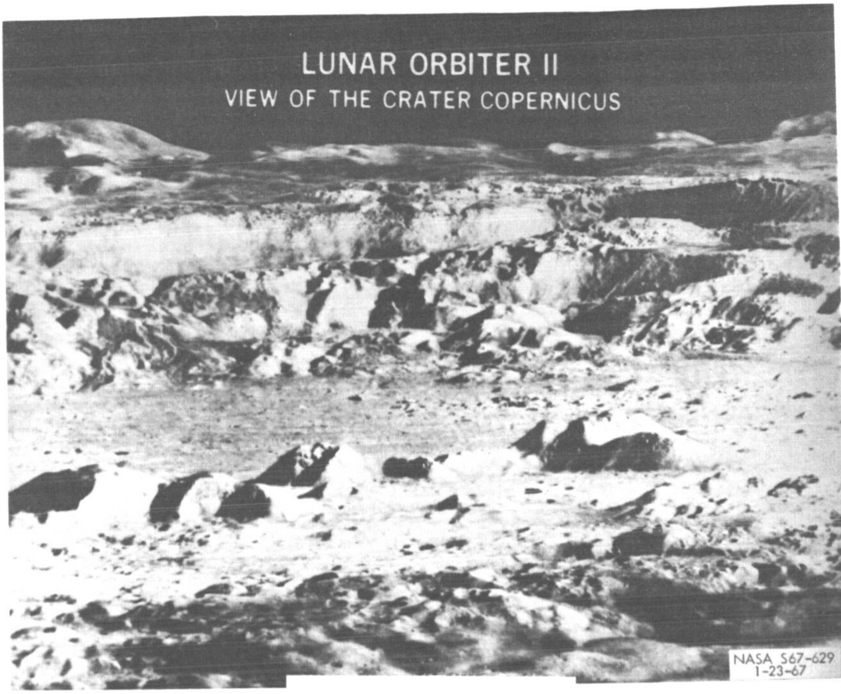


FIGURE 130

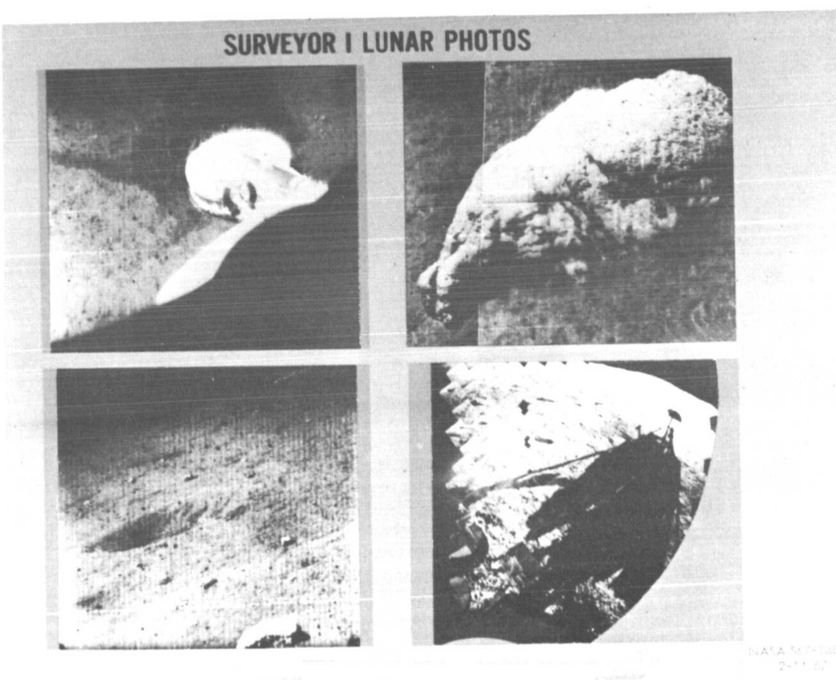


FIGURE 131

tion, by another factor of one thousand (fig. 131). But at that point, because the spacecraft actually landed on the lunar surface and demonstrated the ability to place equipment and instruments on the Moon itself, it brought about the fusion of astronomical and geoscience interests in lunar geologic investigations.

The contribution of space science to planetary geology is reviewed in Appendix VI: "Planetology," by Verl R. Wilmarth, Program Chief, Planetology, Office of Space Science and Applications, NASA Headquarters.

In a similar way, studies of cosmic rays, plasmas, and magnetic fields in space, and of their relationship to the Earth's magnetosphere, have brought physics and geoscience into a close partnership. The physicist finds in the magnetosphere and interplanetary space a gigantic laboratory in which he can study plasmas and magnetohydrodynamics under conditions not afforded to him on the ground. He is even able to conduct some controlled experiments as was done in the generation of artificial radiation belts by high altitude nuclear explosions, or as may be done by flying high energy particle accelerators, and then using satellite instrumentation for measuring their effects on the magnetosphere and upper atmosphere. But in pursuing these studies, the physicist is at the same time tackling problems of great interest to geoscience. These points are discussed in more detail in Appendix IV.

Physics

The principal importance of space to the field of physics is in providing what amounts to a gigantic new laboratory for the conduct of research. We already touched upon this point briefly in mentioning the growing partnership between physics and geoscience. The vacuum of interplanetary space is just not attainable in the Earth-based laboratory. In this vacuum, the plasmas and magnetic fields furnished by the Sun can be used to investigate magnetohydrodynamics, collisionless shock waves, and other phenomena not possible to investigate on the ground. Also, streaming through interplanetary space are galactic cosmic rays of far greater energy than can be generated on Earth in any accelerator now in existence or contemplated. These particles are available to the high energy physicist as research tools in his search for fundamental particles and the ultimate structure of matter.

With satellites and space probes, experiments can be conducted on the scale of the solar system. With our developing manned spaceflight capability, even those requiring the presence of man can be undertaken. Very dense artificial satellites carrying accurate nuclear clocks, can be used to check various aspects of the theory of relativity. Such checks have been carried out on the ground, but the inaccuracies involved make it important to pursue other methods of investigation as well.

The fundamental nature of gravitation is still not understood. The emplacement of high precision corner reflectors on the Moon, to be used with lasers on the Earth to obtain a very accurate determination of the relative positions of Earth and Moon, may permit us to use the Earth-Moon system as a detector of gravitational waves. It is suggested that such waves may be generated by supernovae explosions, in which vast quantities of matter are destroyed by conversion into energy. Or perhaps through other measurements we may be able to detect whether the expansion of the universe has an effect on the value of Newton's gravitational constant, which gives the strength with which matter attracts matter.

Astronomy

One can predict an impact of space techniques upon astronomy as profound as that upon geoscience. Throughout most of its past, astronomy was confined to observations in the narrow visible window (fig. 132), augmented in the last few decades by observations in some of the radio wavelengths. A truly remarkable astronomical theory has been built upon these observational results. But that very theory emphasizes that some of the most important information about the galactic medium and processes, such as the birth, evolution, and demise of celestial objects, is contained in the X-ray, ultraviolet, and infrared wavelengths that are prevented by the atmosphere from reaching the ground.

This is not idle speculation. Already rocket observations have revealed dozens of X-ray sources on the celestial sphere (fig. 133). Such intense X-ray sources were not predicted by astronomical theory, and their discovery has raised numerous difficult questions. The explanation of these sources is one of the major astronomical problems of the day.

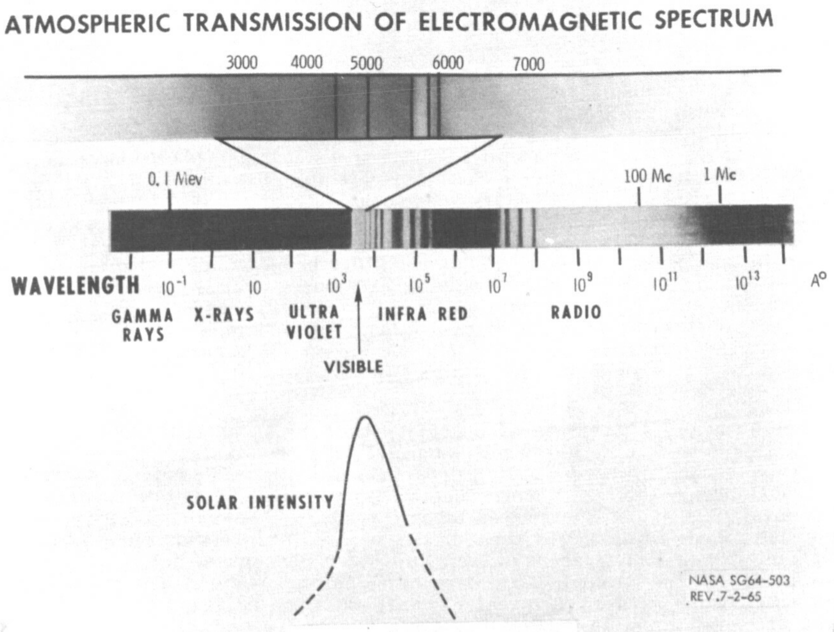


FIGURE 132

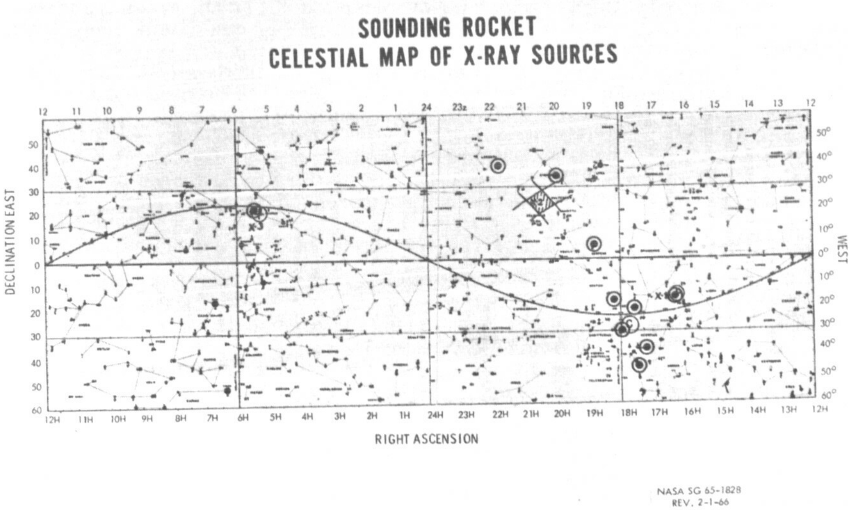


FIGURE 133

The discovery of X-ray sources by space techniques, and of the very puzzling radio galaxies and quasars by ground-based techniques, underscores a very important point. In the future development of astronomy, both ground-based and space techniques must and will become close partners in extending the frontiers of knowledge about the cosmos. Peering some distance into the future, one can visualize an astronomical facility in orbit about the Earth. Like its ground-based counterparts, such as the Mt. Wilson or Mt. Palomar observatories, the orbiting facility would consist of numerous specialized instruments (fig. 134): a large optical telescope for stellar and galactic research, some smaller stellar telescopes, solar instruments, and probably X-ray and radio telescopes. These telescopes would be outfitted with spectographs, coronagraphs, and a variety of detectors in various wavelength regions. The facility would be basically automated, but man-tended. In normal operation, it would be controlled remotely from the ground, and shared by astronomers in much the same way as our facilities on mountain-top observatories. From time to time astronauts would visit the facility, to repolish telescope mirror surfaces, to accomplish routine maintenance operations or make necessary repairs, to update equipment or add new features, and sometimes to conduct photographic astronomical missions. For this last operation, photographic plates would be exposed, using one or more of the telescopes, and then would be returned to Earth for processing and analysis. Such an astronomical facility, once established could remain one of the basic tools of astronomical research for a long time to come.

These points are elaborated in Appendix VII: "Astronomy as a Space Science," by Dr. Henry Smith, Deputy Director, Physics and Astronomy Programs, Office of Space Science and Applications, NASA Headquarters, in which Dr. Smith discusses the important problems of astronomy today and how space astronomy has contributed and is contributing to their solution.

Bioscience

The last of the disciplines that we shall use to illustrate the impact of space research on science is in the life sciences. Space science enters upon the scene

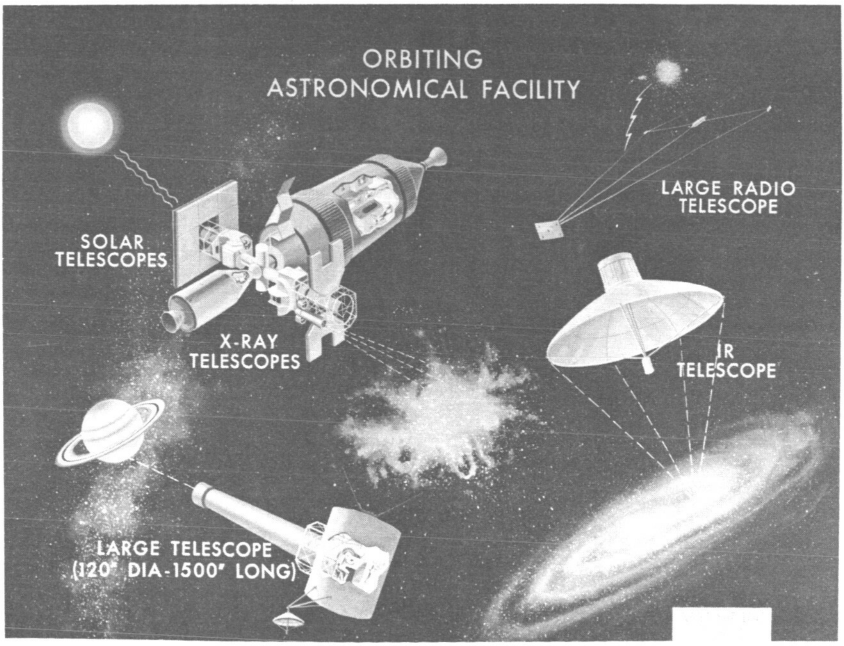


FIGURE 134

at a time when some of the most fundamental questions about the physics and chemistry of life are yielding to the penetrating researchers of modern biology. The fundamental roles of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) in biological materials and processes, the genetic code, and the chemical basis for memory processes, are becoming understood. In this climate the discovery of life on another planet of the solar system would serve to illuminate terrestrial bioscience researches, in addition to having a tremendous philosophical impact.

Life on Earth is ubiquitous. Virtually everywhere we search for it, we find it, often in microbial form. It shows up in the dryest of deserts (fig. 135), and in the hottest (fig. 136) and coldest (fig. 137) of climes. There are even worms that live in glaciers (fig. 138).

Life has existed on Earth for eons of time. Fossils of bacteria have been discovered in specimens of chert (a sedimentary form of quartz) (fig. 139) 3.1 billion years old. Other fossil remains also support the conclusion that there have been living forms on Earth for billions of years.

Life is very persistent. The horseshoe crab of today (fig. 140) bears a remarkable resemblance to the trilobites of half a billion years ago. Some bacterial forms of today appear to have survived through eons (fig. 141). Some forms thrive in what we would regard as extremely hostile environments, such as an atmosphere of ammonia. The organism tardigrade (fig. 142) can be completely desiccated to look like a little flaky crystal, and upon being resupplied with water revives and resumes its normal life cycle.

The chemistry of life is remarkably uniform. The nucleic acids and proteins are invariably basic constituents of living matter. The very complicated DNA molecule, deoxyribonucleic acid (fig. 143), furnishes the means by which genetic information is stored in the cells of living organisms, and by means of which their growth and specialized development are controlled. Many organic molecules have right-handed and left-handed forms. It is an interesting fact that biological substances never use both right and left-handed forms of a specific substance. For example, all living species use left-handed amino acids.

FROZEN SALT LAKE - 12,000 FEET

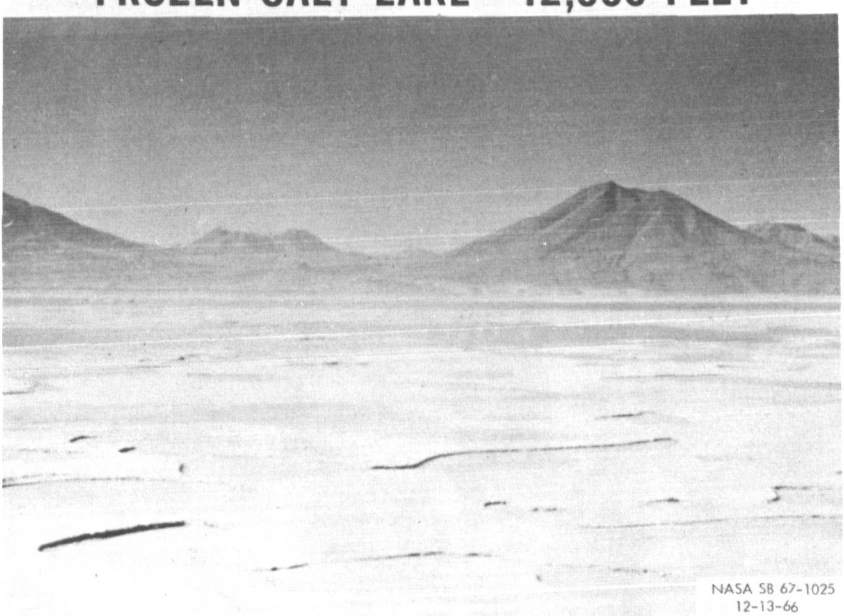


FIGURE 135

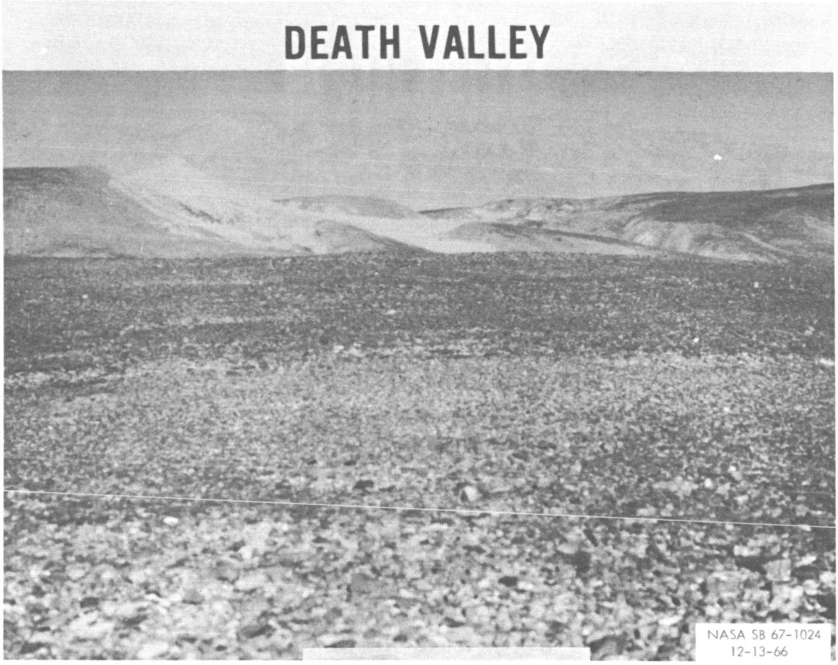


FIGURE 136

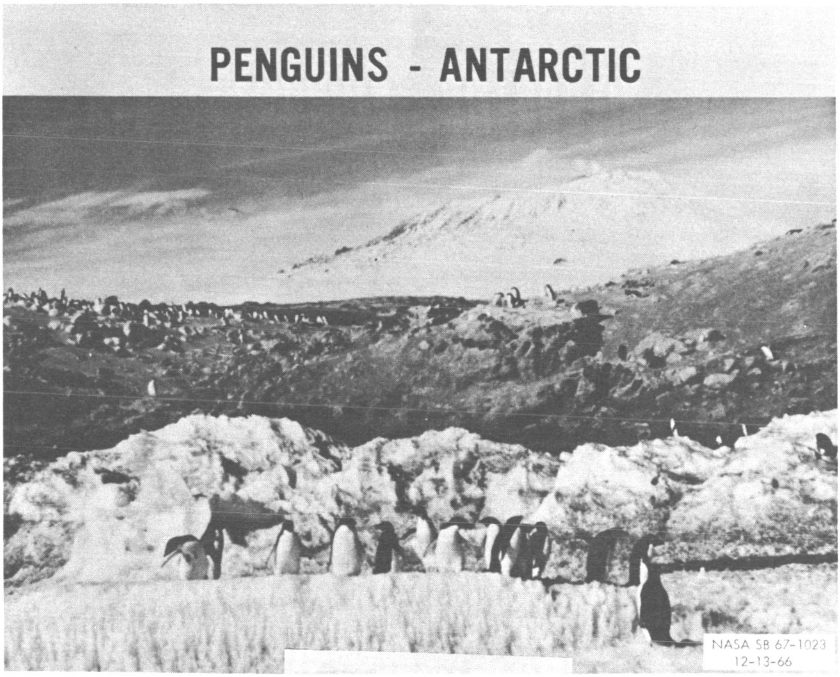


FIGURE 137

FIGURE 138

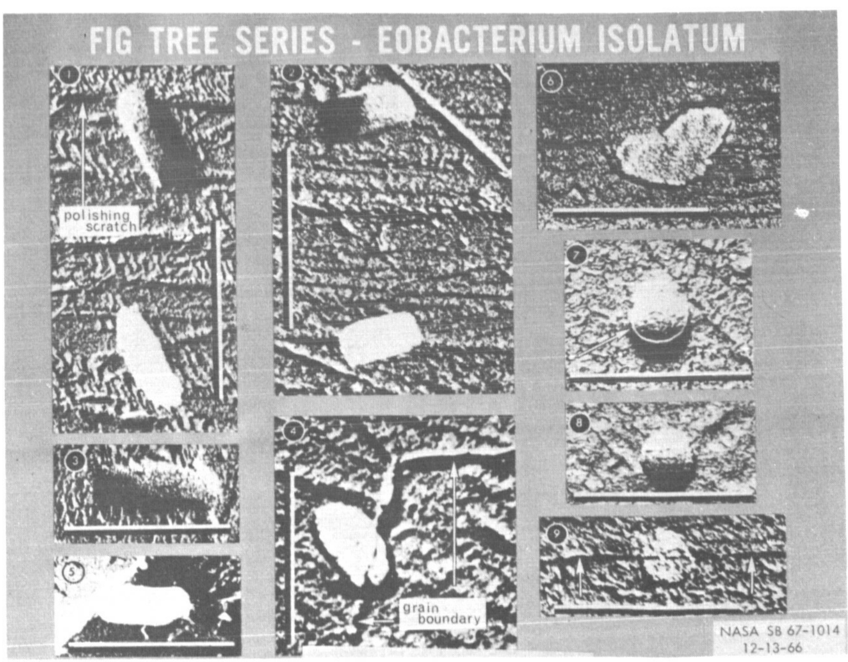


FIGURE 139

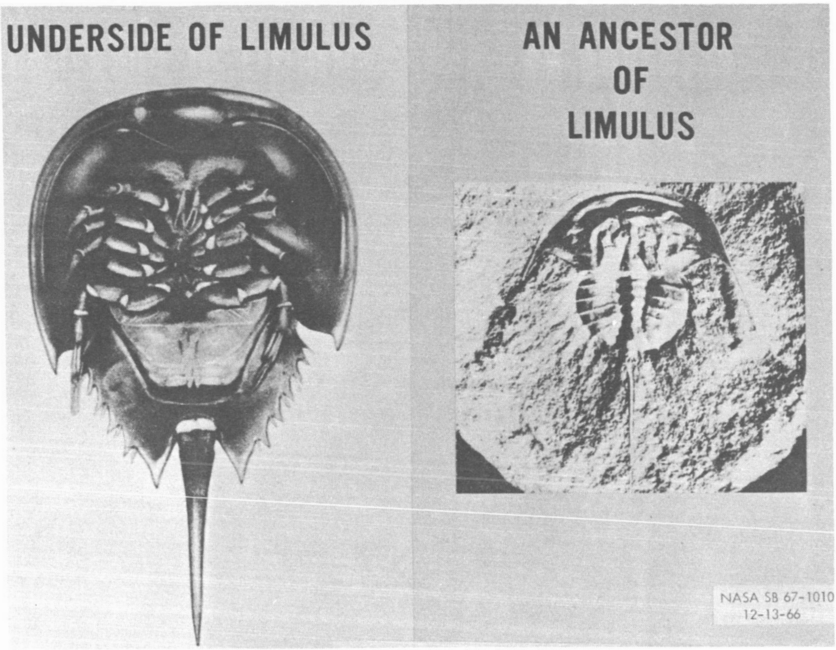


FIGURE 140

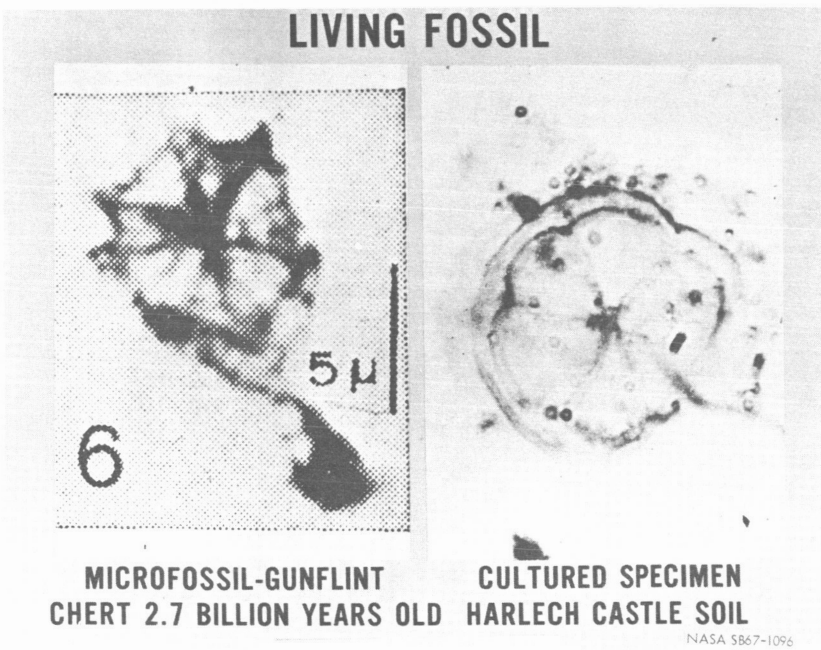


FIGURE 141

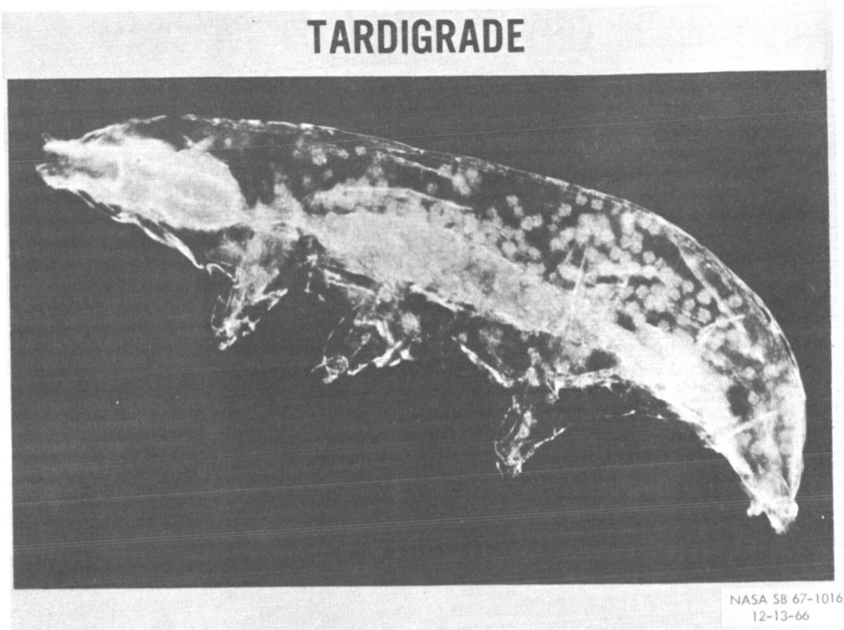


FIGURE 142

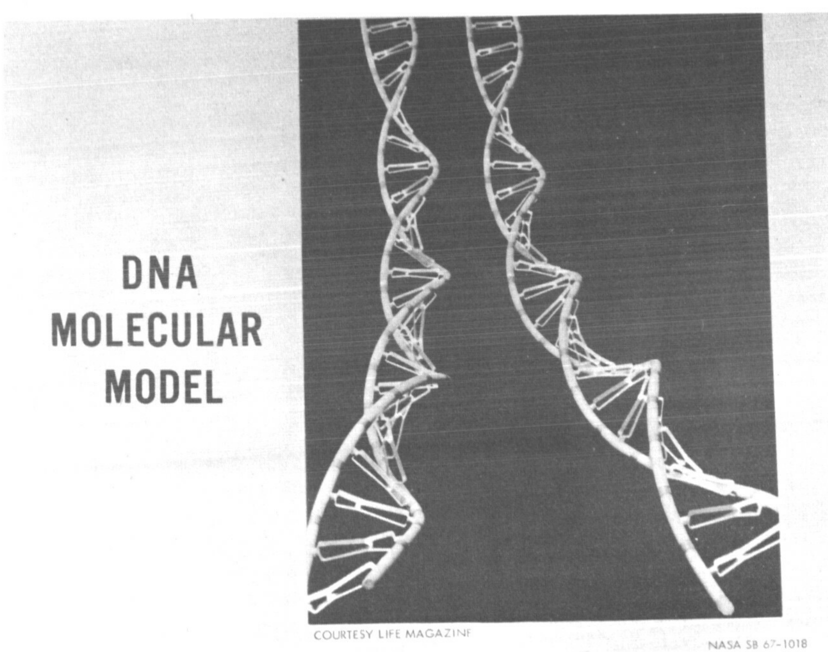


FIGURE 143

In sum, the chemistry of life on Earth is such as to suggest that given the right environmental conditions and adequate time, life will inevitably result. Furthermore, it appears highly likely that the basic chemistry of life will be the same wherever it is found.

This is the framework in which we are investigating the behavior of terrestrial life under space conditions. By sending various forms of life aloft in satellites and space probes, we can search into what are the relative roles of chemistry and of Earth conditions, such as gravitation and the day-night cycle, in the evolution of life and life processes as we now know them.

This is also the framework of interest in the possibility that there may be some forms of life on Mars or Venus. Environmental conditions on Mars may well have been adequate for the formation of life, although the apparent lack of water raises serious doubts in the minds of some scientists. The apparently high surface temperature of Venus, above the melting point of lead, is too hot for life. But some investigators suggest that improved temperature measurements may show that the surface is considerably cooler than most scientists now believe. Others suggest that mountains or perhaps the poles on Venus may provide a temperate environment. In either case, Venus might be capable of supporting the development and preservation of life. Were life to be found on another planet, our experience on Earth suggests that it would be basically similar to terrestrial life in its chemistry. Having been formed under different conditions from those on Earth, however, extraterrestrial life may show some significant large-scale differences. The comparison of this similar, yet somewhat different, life with that on Earth should prove most illuminating to biological research. Moreover, there may be much to learn of the chemical steps toward life on a planet unmodified by the activity of living organisms. Hence, even if life is not found on Mars or Venus, the investigation of the state of evolution of the planet's chemistry will still be important biologically.

Voyager is the long-term program for the exploration of the solar system with instrument unmanned spacecraft. The systematic investigation of Mars is presently a major objective of the Voyager program. The scientific objectives are directed particularly toward obtaining information on the nature and existence of extra-terrestrial life, and the characteristics, evolution, and environment of the planet. The first operational mission in this series is scheduled for the 1973 Mars opportunity. It is currently planned to place the spacecraft in orbit about the planet and to land instrumented payloads on the surface. Subsequent missions to Mars in 1975 and beyond are planned. Missions to Venus and to the other planets are also under consideration.

In the Voyager program special emphasis is directed toward experiments having biological relevance. Virtually all information concerning a planet will have some biological relevance. For example, physical environmental factors such as the range in surface temperatures and the nature of the atmosphere govern the chemical species and reactions which may exist. Deviations from inorganic equilibrium, such as the presence of mixtures of chemical compounds which in the long run are thermodynamically improbable in the absence of life processes, are of extreme interest. The presence and distribution of atmospheric water vapor and of ground water are of crucial importance. The detection and identification of organic compounds in the surface and subsurface materials may provide vital clues to the chemistry of extraterrestrial life, extant or extinct.

Should life be found on Mars or Venus, this will virtually establish the high probability of the formation of life whenever the environmental conditions are appropriate, and make it highly likely that life exists in other solar systems of the universe. Should life not be found on Mars or Venus, this will not establish the opposite conclusion, but rather will simply leave the question still open.

Both lines of research in space biology, i.e., the study of terrestrial life in space and the search for extra-terrestrial life, have potentially far-reaching implications. It is for this reason that, in spite of the deep importance, excitement, and interest of the problems under attack in Earth-based laboratories, a substantial number of competent researchers in the life sciences have chosen to devote a sizable effort to space bioscience. A more detailed discussion of the objectives and opportunities in this important field is given in Appendix VIII: "Space Research and Progress in Biological Science," by Dr. Orr E. Reynolds, Director, Bioscience Programs, Office of Space Science and Applications, NASA Headquarters.

The impact of space research on academic institutions

Space science has become an important field of investigation in our universities. Because of the substance and importance of science problems that we can now attack in the space program, it is essential that we strive to achieve a strong, working relationship, a partnership, with the scientific community. Competent first-rate scientists and their students are interested in and recognize the importance of space science. We are in a position to invest in their careers or in a substantial fraction of their careers.

It is this that we need to do as a country. It is not enough to support an experiment now and then, or here and there. That will not produce the result I believe we seek. The result we seek is a substantial advancement in a number of important disciplines that are bound to underlie our approaches to solutions to practical problems of a technical nature, that will affect and assist us in how we tackle problems of an economic and sociological nature, that will also affect how we view ourselves as we bargain around the political conference table.

The quantum of progress to seek is the reshaping of one generation's thinking into a new collection of concepts for the next generation to reshape in turn. Space science is doing just that in a number of important scientific disciplines as emphasized in the previous section.

Because of the important challenges of space science, over 200 colleges and universities have involved themselves in space research. The major fraction of our space science research is carried out in these institutions. At present, approximately 1500 faculty members and over 2000 graduate students are actively engaged in space science and technology. In addition, under NASA's sponsorship there are at present some 3600 students now studying for doctoral degrees by working on space-related problems in some 30 academic disciplines.

This partnership with the scientific community contributes high-quality research to the space program on the one hand, and enriches graduate education in science and engineering on the other. The effect is also to strengthen the national base of knowledge and understanding, and living competence, which are the fountainhead of all practical technical applications.

The practical importance of space science

Following this presentation will come a review of practical applications of space knowledge and technology. The value of such applications is clear in the very telling of them. The import of the investment in them is immediately understandable in the direct way in which they meet human needs and aspirations. Yet basic research, of which space science is an important segment, is equally important to the total well-being of our nation. I should like in the next two sections to develop this point further to explain why we so urgently request your support of a balanced, vigorous, space science effort as an essential part of our total national space program.

What is science?

It is with considerable trepidation that I have attempted in the few pages of Appendix IX to define what science is. Many authors, themselves illustrious scientists, have undertaken this task, and have considered it necessary to devote whole books to the subject. It is a way of life, not always understood by those who do not live it. Yet, its influence rests upon all of modern society, being seen not only in the objects of everyday living but also in our concepts and patterns of thought.

Science is a dynamic activity. It is not a static collection of facts and ideas. It is the process by which scientists, individually and collectively, work together to devise a commonly accepted explanation of the universe about them. It involves observation and measurement, imagination, induction, hypothesis, generalization, deduction, test, communication, and mutual criticism, in a never ending round of assaults on the unknown or poorly known.

The scientist observes and measures objects and phenomena of the physical world. To experimental results he applies imagination in an effort to discern or induce laws of action or behavior of matter and energy. He generalizes from the collection of observations and measurements, and relationships and laws, that he has accumulated, to develop theories that can in some coherent way explain what is going on. Theories are then used to predict new phenomena and new laws as yet unobserved, and these predictions serve as guides to new experiments and observations.

The scientist maintains a continual communication with his colleagues in a variety of ways subjecting his results to the close scrutiny of his peers. This communication is carried out through the scientific literature, in scientific meetings, and in informal meetings scientist-to-scientist. So important is the role of communications among scientists, in the process of mutual criticism which it serves, that one author was led to assert that modern science *is* communication.

This process or activity that we call science has developed its rules on the basis of hard and searching experience. Recognizing that physical science cannot attain the absolute in knowledge, the scientists have sought to substitute for the unobtainable absolute the attainable utmost in objectivity. The scientific tradition, while demanding of each individual the maximum of insight, ingenuity, imagination, discernment, and invention,—that is, the utmost in subjectivity,—nevertheless wrings out as much of the personal equation as possible in demanding that the individual subject his thoughts and results to the uncompromising scrutiny of his skeptical peers. This tradition the members of the scientific community accept without reservation. This acceptance gives to science and scientists a unity not only of knowledge but of method that encircles the world and transcends political divisions.

This then is the process by which scientists throughout the world join hands, as it were, in advancing human knowledge. This is the process from which come the knowledge, ideas, and principles used in practical applications of a technical nature. Moreover, just as practical returns stem from scientific research, so does scientific research benefit from the practical results of applied research and development. The achievements in electronics, power supplies, structures, materials, rockets, etc., contribute fully as much to the advancement of scientific techniques as results of science did to make the engineering achievements possible. In this partnership of science and technology and engineering, science plays a role of especial importance to our society.

The importance of science in our society

The reward of knowledge is in practical benefits to be found throughout the world. In addition to these tangible benefits are the intangible ones of increased understanding on the part of humans of their place in the scheme of things. The battle against ignorance is a never ending one, but each new concept, accepted as the result of increased understanding, has its beneficial influence on the enlightenment of mankind.

Today, many of the world's population are aware of the world as a body of a solar system in a galaxy among millions of other galaxies. These people can perceive of man in a historical and cosmological perspective that did not exist in centuries past. It may be hoped that, as this understanding and these concept spread to more and more of the world's people, this common bond of understanding will give not only increased motivation to solve peaceably the problems that beset the world, but also increased means for doing so.

Recently a colleague of mine had occasion to review the history of research into the nature of electricity. A sketch of that history is attached as Appendix X: "A Brief History of Research in Electricity," by Dr. John Naugle, Deputy Associate Administrator for Space Science and Applications (Sciences), NASA Headquarters. The story illustrates many important points.

At first, progress was slow and sporadic. Early results appeared largely unconnected. The times when new ideas and observations would appear were unpredictable, as were the sources. Many people from many countries made fundamental contributions. Because of the wide geographic range of contributors, no individual or group was in a position to halt, by a unilateral decision, the flow of new knowledge about electricity.

Perhaps the most startling lesson is that for centuries electrical research had no apparent practical value. From 600 B.C. until Christmas Day, 1821, when Faraday constructed the first primitive electric motor, no substantial practical application of the gradually accumulating knowledge of electricity was apparent, even in concept. Ten years later, in 1831, Faraday showed that a voltage could be generated by moving a conductor through a magnetic field, and thus established the basis for the electric generator. Since that time how fabulously, extravagantly, overwhelming productive research into the nature of electricity has been: The electric motor, electric power, refrigeration, air conditioning, lighting, heating, automobile ignition systems, electronics, radio and television, industrial process controls, automation techniques, and mammoth computers, are

but a mere beginning to a long list. In a very real sense the nuclear age is an extension of research into the nature of electricity.

Such stories could be told in other fields: mathematics, mechanics, physics of fluids, states of matter, the geosciences, chemistry, and biology to name but a few. Similar lessons may be drawn from all these histories. Chapter X of A SHORT HISTORY OF SCIENCE, Doubleday Anchor Books, 1959, contains some very perceptive observations by Dr. F. Sherwood Taylor, Director of the Science Museum, South Kensington, London, England. I should like to quote Dr. Taylor:

"There is . . . always some time-lag between the discovery of a scientific principle and its use to satisfy human needs . . . Thus we shall find that it was principally eighteenth-century science that was utilised by the industry of the early nineteenth century, while the great discoveries of the time bore fruit only in the middle and later years of the nineteenth century.

". . . the application of the first principles of the science of heat to the crude pumping engines of the mid-eighteenth century had enabled James Watt, after 1780, to produce efficient engines which could turn the wheels and shafts of hundreds of machines. Just before the nineteenth century began the world came to realise the possibilities of the steam-driven machine, and for fifty years after, the story of industry is making, improving and finding uses for steam engines."

"We may say, indeed, that the electrical discoveries of the period 1800–1835 became fruitful only in the period 1870–1900."

"Again, one of the greatest discoveries in physics, the demonstration that light . . . has the character of a transverse wave-motion, was made in the years 1800–1820; but this discovery scarcely had any effect upon the optical industries until the closing years of the century."

"In the years between 1803 and 1808 was made the greatest advance in the history of chemistry—the atomic theory of John Dalton . . . The atomic theory led at once to the idea of chemical equivalents and formulae; these were the foundation of the theory of chemical analysis, which made possible the scientific control of the chemical industry . . . Yet . . . it was not until the 1850's . . . that the atomic theory had its triumph, serving in its new form to evolve the wonderful structure of organic chemistry, with its beneficent drugs, beautiful dyes—and destructive explosives."

A vigorous, balanced, national effort in basic research inevitably leads to a rich harvest of practical applications. Both the source and timing of those returns are not predictable in advance. It is usually a slow process for new knowledge and concepts produced by basic research to work their way into practical uses. Nevertheless, all practical technical applications rest on a broad and fundamental understanding which only a healthy and continuing program of basic research can attain and maintain. History fully substantiates this point. In NASA, our Technology Utilization Program is designed not only to speed up the feedback from space research into other areas of technical application, but also to document the process and its results. By its very nature that program can, at most, uncover only a small part of the total return. Yet, what it does reveal is quite impressive.

For several years now, we in the Office of Space Science and Applications have provided a list of both factual and potential practical benefits from basic and applied research throughout the NASA Program. While recognizing that we cannot predict with certainty, we have, nevertheless, permitted ourselves to speculate on ways in which results from the various scientific disciplines may well find their way into solving practical problems.

Our list for this year is contained in Appendix XI. The examples and ideas came from NASA Centers and other sources. We have listed the benefits under several headings: national security; industry and manufacture; construction industry; communications; weather; power sources and public utilities; transportation and commerce; health and medicine; Earth resources; food and agriculture; science; education and welfare; social and political. I believe the Committee Members will find Appendix XI well worth reading.

In particular, I should like to call attention to a letter from Dr. Edwin G. Schneider, Vice President-Engineering, Sylvania Electronics Systems. Dr. Schneider speaks from extensive experience with Department of Defense and NASA contracts. He writes in part: "It is my belief that the technology being developed under NASA and DoD contracts is being applied to commercial products at a rate which is limited only by the ability of engineers to assimilate the

knowledge and ability of industry to carry new product ideas all the way through to the market place . . . The concern expressed by various groups over the apparent lack of transfer of technology from NASA and DoD appears to me to be based on an imperfect understanding of the engineering process and an unwarranted expectation that much of the transfer will be easily recognizable as hardware end items." Dr. Schneider identifies publication of new information in the technical literature, interchange of duties of commercial engineers between government and non-government work, and the stimulation by government to industry to support their own development of new and more capable devices as being the primary means of transfer. These comments confirm our belief that much transfer occurs that is not and can never really be identified. The listings developed in the NASA Technology Utilization Program, and the examples included in Appendix XI lend support to Dr. Schneider's position.

Much of the harvest from today's investment in basic research will be reaped by our children and our grandchildren. In fact, what we are accomplishing in basic research today constitutes a legacy which our descendants have a right to expect from us. Just as today's technical capability rests on yesterday's research, so will tomorrow's capability rest on today's research.

As we give strong support to applied research and development, because we can see clearly the practical return and expect to enjoy it soon, we must remember to sow the seed for the more distant harvest. We must keep alive the understanding of the vital, fundamental, indispensable role of basic research in continuing technical strength, and sustain the patience needed to make and maintain the necessary investments in basic research.

The United States leads in science today. We lead in space science. It is a leadership that we have earned, and must earn again, and again, or lose it. It is a leadership that is under constant challenge and can easily be lost through apathy and undernourishment, and with it technological leadership.

With your support I believe we can maintain our lead. But it will not be easy. The Soviet pace in planetary exploration, and their mounting pace in exploration of the Moon pose a real challenge that we can meet only by maintaining the momentum we have built up in our own space program. We ask your support of the President's budget that we may follow through on the good start that the United States has made.

CHAPTER II. SPACE APPLICATIONS PROGRAMS

It is very clear to many of us that the fundamental scientific knowledge evolving from the National space program will have a profound effect on the life of man in the future. There is in addition a very great potential for the immediate application of space, satellites, and man in space to solve some of the problems which man faces here on Earth today—or will face very shortly. It is this area of NASA's activities that we refer to as the Space Applications Program.

To paraphrase Socrates speaking about 400 B.C.: "We who inhabit the Earth, dwell like frogs at the bottom of a pool. Only if man could rise above the summit of the air could he behold the true Earth, the world in which we live." ("Phaedo" by Plato, E. P. Dutton & Co.) Socrates could hardly have understood how prophetic his statement of 2400 years ago was, for it has only been in the last few years that we have been able to rise above our atmosphere and fully appreciate the power of observing our own Earth from that vantage point.

I'm sure that most of us have become familiar with some of the potential uses of satellites in the fields of communications and meteorology, but we have just begun to appreciate the real potential in these fields, as well as the possibilities in many others such as geodesy, geology, hydrology, cartography, navigation, air traffic control, oceanography, and even geography.

I should like to review for you briefly some of the more apparent potential practical uses of space. Figure 144 categorizes the applications into four major groups: Geodesy, Communications and Navigation, Meteorology, and Earth Resources Survey. I will speak to each of these in turn, but would like at this time to call your attention to the fact that there are many applications or services that can be provided by satellites under these four general headings. Note, for instance, the many kinds of communications services listed, each requiring unique consideration and a varying challenge in technological development. This list is for your reference and is intended to point up the fairly large

SPACE APPLICATIONS

- **GEODESY**
  - WORLD GEODETIC REFERENCE SYSTEM
  - DEFINE GRAVITY FIELD
- **COMMUNICATIONS & NAVIGATION**
  - POINT-TO-POINT INTERCONTINENTAL
  - SMALL TERMINAL MULTIPLE ACCESS
  - NAVIGATION-TRAFFIC CONTROL
  - DATA RELAY: EARTH - LUNAR - PLANETARY
  - VOICE BROADCAST
  - COMMUNITY TELEVISION
  - TELEVISION BROADCAST
- **METEOROLOGY**
  - DAY & NIGHT CLOUD COVER
  - CONTINUOUS OBSERVATIONS
  - ATMOSPHERIC STRUCTURE FOR LONG RANGE FORECASTS
- **EARTH RESOURCES SURVEY**
  - GEOGRAPHY & CARTOGRAPHY
  - GEOLOGY & MINEROLOGY
  - AGRICULTURE & FORESTRY
  - WATER RESOURCES & POLLUTION CONTROL
  - OCEANOGRAPHY

NASA SA 67-2017
2-27-67

FIGURE 144

number of very practical potential applications of space which are currently under some degree of consideration. I am sure that it is by no means a complete list of possible space applications, for use of the vantage point of space is still in its infancy and we have yet to visualize many of its potentials. Perhaps, as Socrates suggested, it is only through being in space that we shall fully understand the Earth and the uses to which we can put this vantage position of space.

Geodesy

Until 1958 the progress in defining the shape of the Earth was slow. The Greeks at about 600 B.C. (fig. 145) postulated a spherical Earth and estimated the circumference with remarkable accuracy. The next step did not occur until the 17th Century when Sir Isaac Newton recognized the flattening of the Earth at the poles. But the next real advance had to wait for the space era.

The use of satellites for geodetic purposes falls into two categories as shown in Chart SA67-2017. First, to establish a common world geodetic reference system and secondly, to accurately define the gravity field of the Earth.

A common geodetic reference system bears directly on our ability to map the surface of the Earth. The cartographers have long been plagued by the fact that there does not exist a single reference system today, but instead there are about 80 more or less independently derived reference systems called datums (fig. 146). Satellites are being used today to tie these independently derived datums together with accuracies commensurate with those of the individual datums.

Of equal importance to the determination of the size and shape of the Earth is a definition of its gravity field. One of the most important scientific con-

SIZE, SHAPE, AND GRAVITY FIELD, OF EARTH

THROUGH SATELLITE GEODESY

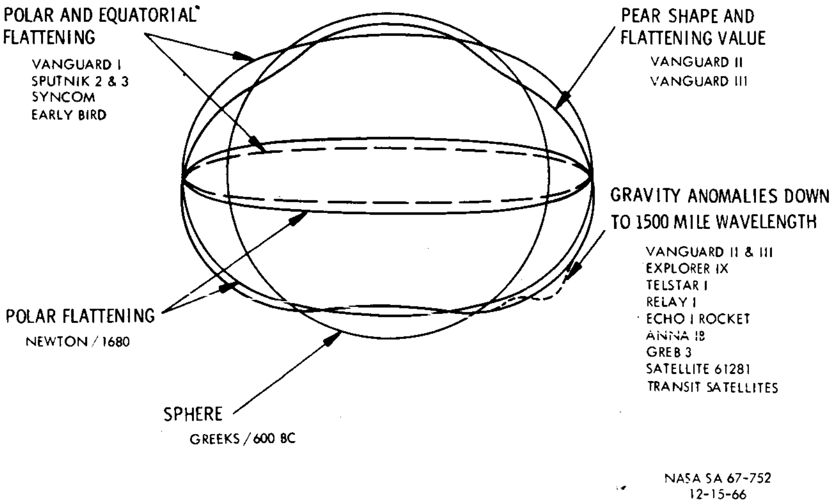


FIGURE 145

GEODESY MAJOR WORLD DATUMS

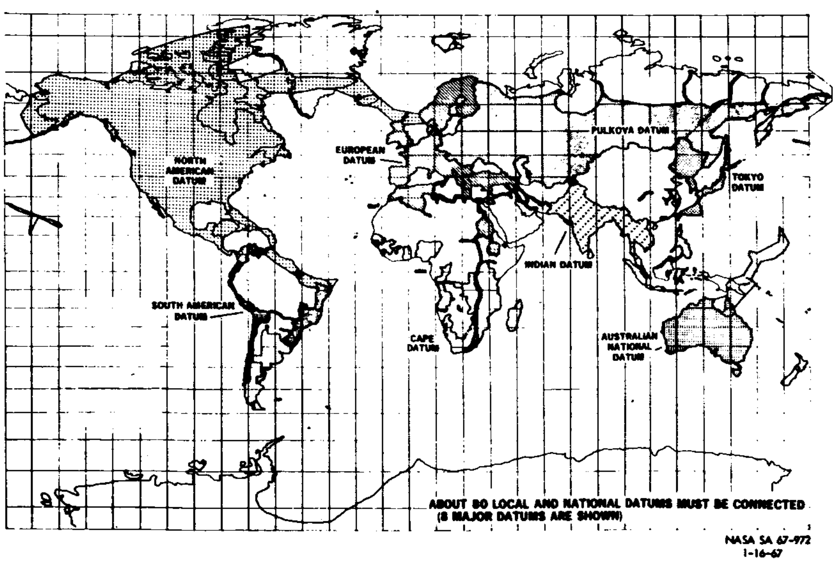


FIGURE 146

tributions of satellite geodesy has been the determination of the large scale features of this force-field. The primary result of this determination has been to raise questions. Through attempts at answering these questions, satellite geodesy has had an appreciable impact on the direction of scientific investigation in many areas of the Earth Sciences. As an example: one of the first results of satellite geodesy was an improved value for the flattening of the Earth which was determined to be significantly greater than that derived from the best theory available. Suggested explanations have ranged from a gradual decrease in the Earth's speed of rotation to a lag in the Earth's adjustment to the ending of the last ice age. The resolution of this inconsistency between the measured and theoretical values has important implications with respect to the present structure and strength of the Earth's interior and its past history.

Our space operations, too, are dependent upon the accurate description of the gravity field. As this description improves, we improve orbit predictions and orbit control. We will also be able to know more precisely the position of our satellites in space and how to separate the effect of gravity on the satellite from other effects of the environment such as those of air drag and solar radiation.

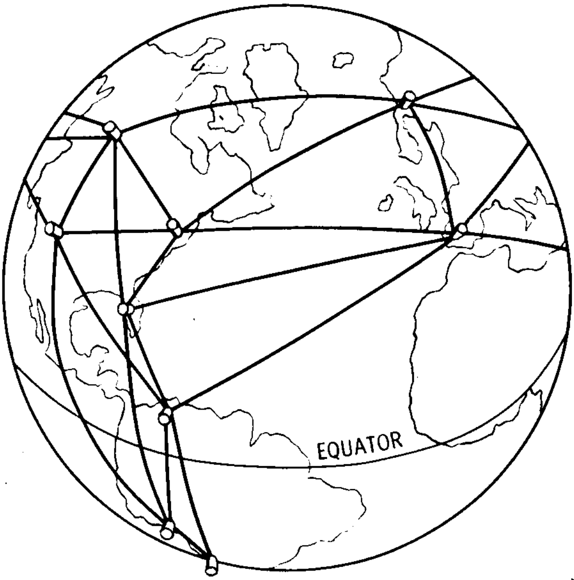
We are well on our way toward the establishment of a World Geodetic Reference System with an accuracy of 10 meters. By using such satellites as Echo I and II, Pageos, and GEOS-I, a great deal has been accomplished toward this goal over the past year. We have established the relative positions of 12 of the required 75 control points (fig. 147) around the Earth with the required accuracy and expect to establish several more with the data obtained in 1967.

We have also in 1966 made strides in geodetic instrumentation accuracy which shows promise for the future. This improved accuracy might be of appreciable assistance if applied in the future in the determination of the shape of the ocean

OBJECTIVE 1

(ESTABLISH A WORLD REFERENCE SYSTEM)

RELATIVE POSITION OF 12 CONTROL POINTS DETERMINED



NASA SA 67-1225
12-13-66

FIGURE 147

surface, the tracking of land motions (Earth tides), and in the support of our Earth Resources Survey and Earth Sciences Programs.

The geodetic program is not only a cooperative effort between many agencies of our government but, in addition, geodesy has traditionally served as a basis for international cooperation. Satellite geodesy has furthered that tendency. Through such organizations as the International Union of Geodesy and Geophysics (IUGG) and the Committee on Space Research (COSPAR), many nations are continuing to work together to set down requirements, plan observational programs, and share results.

Communications and navigation

We are all familiar with the fact that we have already established the technology for the use of satellites for large volume point-to-point or intercontinental communications. The current satellite systems are bringing about healthy competition with the older conventional systems such as cables; this is evidenced in recently reduced cable and combined rates, a long-term saving that comes back directly to the individual citizen. We are proud of the role that NASA has played in the development of this new industry and we are continuing to support the launches required by the Communications Satellite Corporation as stipulated in the Communications Satellite Act of 1962.

But the potential uses of satellites in the broad area of communications are many (fig. 148); the ultimate and complete potential is probably beyond our ability to predict. We can, however, foresee the extension of the advantages of satellites for communication between smaller and smaller ground terminals in larger and larger numbers. Today, economic use of satellites is restricted to large volume traffic through a rather small number of very large ground terminals which cost millions of dollars. Foreseeable increases in satellite size and power will permit economical direct participation by even larger numbers of smaller traffic-producing areas in satellite systems. Achievements of large-scale multiple access to relatively small and inexpensive Earth terminals could ultimately make it economical for many more areas and nations to have their own Earth terminals. This direct access to a global satellite system would eliminate the need to cross political boundaries and territories for such access.

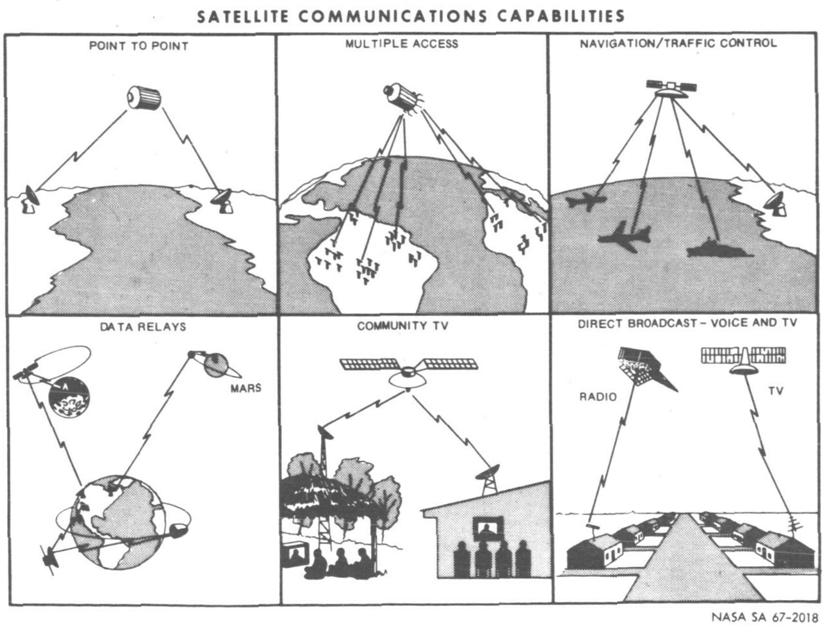


FIGURE 148

If we carry this small station capability one step further and combine it with a position determination capability using that same satellite system, we can foresee the development of an air and sea navigation and traffic control satellite system in combination with normal communications functions. Such a capability is already needed on the North Atlantic air routes to permit a closer and safer spacing of aircraft within the optimum air lanes and to provide up-to-date weather and sea state information to pilots and ship captains in order to improve the economy, comfort, and safety of their journey. In the case of accidents or other emergencies, this communications and location capability could be of great help in alerting rescue forces to the emergency and in directing them accurately and expeditiously to the scene for rescue operations.

We have already moved a long step forward in our ability to communicate with small terminals and with aircraft with the technology being developed in our current Applications Technology Satellite program. ATS–I is being used in experimental programs to develop our multiple access communications capability and our ability to communicate with aircraft, as shown in figure 149. Nine commercial airlines, both foreign and domestic, as well as the Federal Aviation Agency and the Department of Defense, are participating in this part of the ATS program, and are developing their own aircraft equipment and techniques for working with satellites.

It is also quite likely as we go to more sophisticated spacecraft in our space program for lunar exploration, and interplanetary and galactic exploration, that we shall need the help of data relay satellites to provide for the high communications capacities required. A data relay satellite system about the Earth could minimize the requirements for continuing expensive major additions to the global network of tracking, command, and data acquisition stations. It could preclude the necessity for carrying on board satellites the data recorders which are currently necessary because many satellites are out of sight of data readout stations for a large percentage of their orbits. Such recorders have been a constant reliability problem in our current scientific and applications satellites, and have often been the limiting factor in useful satellite lifetime.

FIGURE 149

Lunar and planetary orbiting data relay satellites could provide for continuous communications with orbiters and landers when they are obscured from the Earth, and could minimize power required on board the research spacecraft or lander for communications over the interplanetary distances back to Earth.

As our ability to fly larger spacecraft and carry more power into space progresses, it will be possible to provide for television transmission for community services, i.e., to specially designed receivers at costs that might be practical for use by schools, or for viewing by groups of people, or perhaps in villages where such services are sorely needed. The capability could be achieved without the many ground transmitter stations required today to cover large areas.

As we progress further, the direct broadcasting of voice or eventually even television through a satellite to conventional radio or television sets in the home may be possible. The satellite size and power requirements for the latter dictate that such systems cannot be made available until near the end of the next decade.

We recognize the many policy problems involved in many of these applications of space, such as broadcasting. The United States is studying and developing the potential and the technical possibilties in these areas and is seeking technical solutions to minimize problems of international and political concern. In this regard, NASA plays an active role in advising other agencies of the Government on these applications.

In addition to being of potential economic benefit to the United States and the other advanced nations of the world, exploitation of this application of space could result in important political and social benefits to developing nations. A voice or TV direct broadcast capability could bring the advantages of modern mass communications to regions lacking adequate broadcasting networks for educational and informational programs. This could provide modern teaching techniques to these areas, provide education in elementary health and hygiene, and encourage tendencies toward regional cohesion, especially toward the use of a common language in areas where many languages or dialects are currently in use. In pursuing the development of such a capability the United States could demonstrate to the world the vigor of our space research and development effort, and our willingness to use our strengths on behalf of those developing nations which are currently unable to participate in space activity.

Finally, an important aspect of our effort in space communications is to determine how we can conserve one of the Nation's and the world's most valuable resources—the radio frequency spectrum. The spectrum is, after all, absolutely limited by physical laws. With space systems we may be able to use effectively areas of the spectrum not usable with Earth-based systems. By more effective utilization of those frequency bands in which the space systems are efficient, we can minimize the Earth-based system use demands on the spectrum. As a matter of fact, in some cases we have found it possible with our satellite systems to share frequencies with Earth-based communications services. Thus we can make dual use of areas of the spectrum without interference between ground and space systems. NASA works closely with the Office of Telecommunications Management of the Office of Emergency Planning, and its Interdepartmental Radio Advisory Committee; and the Federal Communications Commission on these matters.

Meteorology

Meteorology is another major field that has already utilized the vantage point of space in an operational system. This operational system provides daily observation of the global cloud cover (fig. 150). This cloud cover is the most visible and dramatic indication of the dynamic state of the Earth's atmosphere. In addition to a determination of large scale atmospheric circulations, delineation of jet streams, mountain lee waves, and wind shears; such presentations reveal storms and the type of the storm, and permit monitoring the progress of storms from creation to dissolution, thus providing a sound basis for issuing warnings. One of the most striking benefits accruing from our current satellite view from above is our ability to observe the birth, progress, and death of the kind of major storms that leave major disaster in their wake when they are unforeseen.

In 1966 we saw the establishment of the operational satellite system for the Environmental Science Services Administration (ESSA) based on satellites and instruments developed in the TIROS and Nimbus research programs. The role played by the operational system in weather forecasting is indicated schematically on figure 151. This chart indicates the relationship between storm size and the period over which its behavior can be predicted and indicates by the stippled area the capabilities of our current operational systems including the TIROS

FIGURE 150

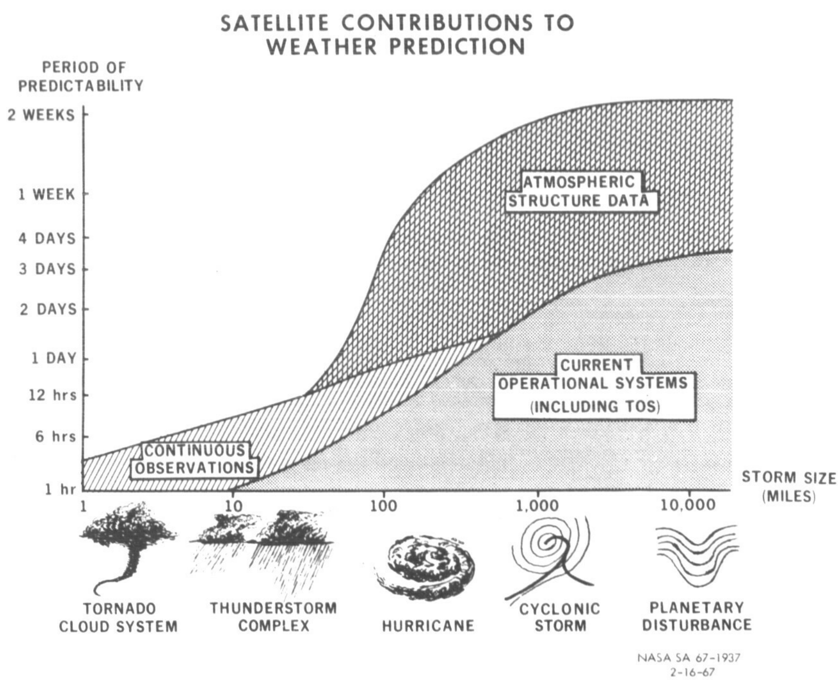


FIGURE 151

Operational Satellite (TOS) or ESSA satellites. The extension of these capabilities as indicated by the barred and cross-hatched areas will be discussed later. The current systems permit forecasting the behavior of larger scale weather phenomenon including storms of the scale of hurricanes and cyclones over a period of one or two days.

The quality of the predictions within this stippled area will be improved greatly when nighttime cloud cover observations become available. The period between observations of a particular area would then be reduced from 24 hours with the current daylight cloud cover observations to 12 hours with both a day and a night observation. The changing characteristics and behavior of storms could be more closely monitored and their future behavior predicted. Such a nighttime cloud cover observing capability was developed in the Nimbus program and will be incorporated in the next generation of operational meterological satellites towards the end of this decade.

The current operational system supplies only periodic observations of a given location. However, many of the most violent but small scale storms such as tornadoes and thunderstorms have durations of only a few hours, and can develop, wreak havoc, and dissipate without being observed by such satellites. To provide adequate warning of these storms, there must be a capability for continuous observation of localized phenomena. A satellite in synchronous orbit offers the potentiality for the required continuous observations and would permit short term forecasting of these events as shown in the barred area of the chart. Dramatic progress was made toward developing this capability in 1966 with an Applications Technology Satellite, ATS–I. The camera system used was a spin scan variety and provided frequent pictures of the whole Earth's disc. Pictures can be taken with this camera system every 20 minutes, if necessary, to watch and measure the progress of the weather. A sequence of pictures taken 23 minutes apart on January 24, 1967, is shown on figure 152. Although the general features appear to be unchanged, a detailed examination of these pictures reveals that some changes are taking place, e.g., the clouds are decreasing to the right of the center of the major storm located in the upper left of the photographs, starting with the one

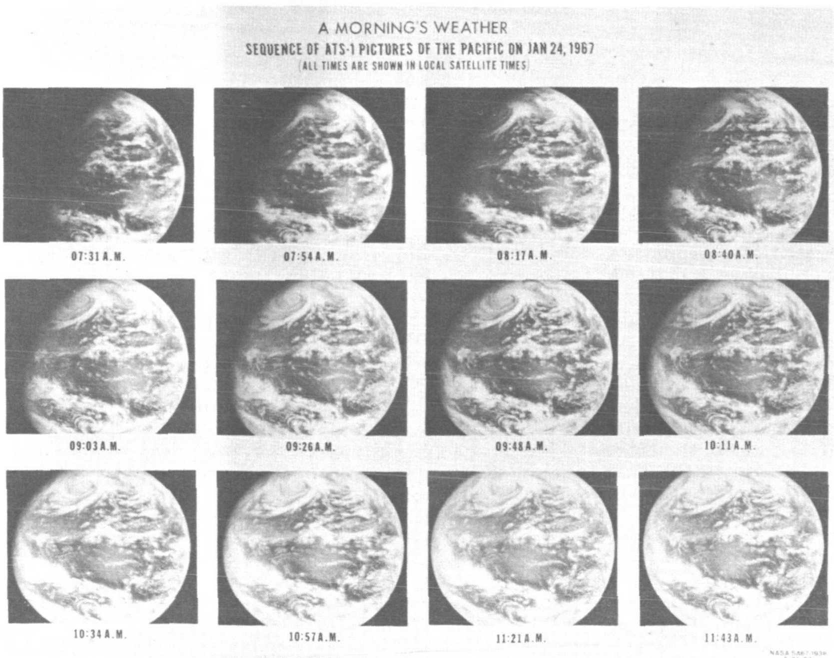


FIGURE 152

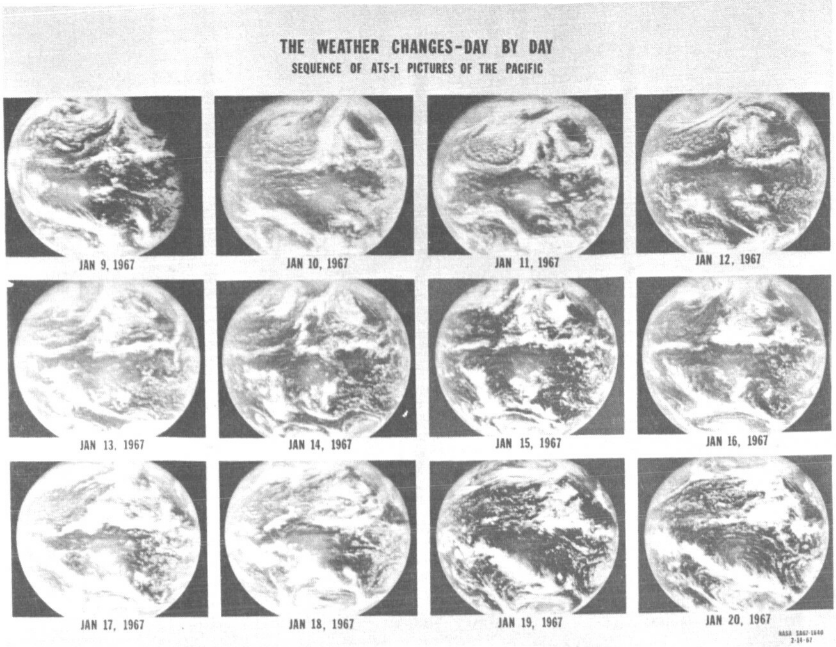


FIGURE 153

labeled 09:03 A.M. Though this type of data is very new, some progress has been made toward determining wind speed and direction from such pictures. Another aspect of these pictures appreciably more obvious to the untrained eye is the weather changes that occur day-by-day as shown in figure 153. This sequence clearly shows major weather patterns moving, disappearing, and reforming on a daily basis. The great potential value of observations such as these has been recognized and forms the basis for plans for the establishment of a synchronous operational meteorological satellite system.

While the short range predictions of the weather are important to our daily activities and in the saving of lives and property, the utility of that service would have a many fold increase if such predictions could be extended over a longer period, perhaps as much as two weeks or more.

The National Academy of Sciences-National Research Council in a 1965 report estimated the potential savings to the United States alone as a result of such long range forecasting could approach 2½ billion dollars annually (Economic Benefits from Oceanographic Research, NAS–NRC Publication 1228, 1965).

The ingredients needs to provide these forecasts are an adequate model of the atmosphere, sufficiently large computers, and quantitative measurements of the atmospheric structure including such parameters as pressure, temperature, moisture content, and wind velocity at various altitudes on regular periodic schedules over the entire Earth. Atmospheric models exist and with additional empirical data can be refined. Computer technology exists today. It remains only to develop techniques for the acquisition of the atmospheric structure data (as indicated in fig. 151) to make possible the 1 to 2 week forecasts of larger scale weather.

The World Weather Watch (WWW) Program was established by the World Meteorological Organization (WMO) in recognition of the possibility of realizing accurate extended forecasting. Basic to the implementation of the WWW is the development of the appropriate satellite systems. It is the prime purpose of the Nimbus research satellite program to develop this technology. In this program techniques and sensors are being developed to probe the atmosphere re-

motely and directly. Using the radiation emitted, absorbed, and reflected by the Earth and its atmosphere, satellite instrumentation will provide the measurement of the required parameters of the atmospheric structure.

Earth resources survey

As the world's population continues to grow, our need to develop, protect, replenish, and use our natural resources wisely becomes more apparent and urgent. The air and atmosphere are resources of the Earth as are the oceans, fresh water, ice packs, forests, minerals, tillable land, etc. Efficient utilization of these resources not only includes discovery and management, but also detection and control of pollution which is becoming an extremely important factor. In many areas this need is reaching crisis proportions. Fortunately, with the advent of the space age, new techniques are being discovered and developed to assist us in meeting this crisis. For nearly two years now, we have been exploring the use of both manned and automated spacecraft to develop the potential of flying instruments in space that will permit unique observations of the state and condition of our agricultural, water, forestry, mineral, land, and marine resources. These can be used by resource managers for effective decisionmaking. Much of our work to date has been done with aircraft, and with information which we have been able to extract from data obtained by existing satellites such as TIROS, Nimbus, ATS, and, of course, from the valuable photographs taken by the astronauts of the Mercury and Gemini programs. Based on this experience it appears that the vantage point of space offers a number of unique advantages for Earth resources surveys, and we intend to pursue these advantages vigorously.

In the areas of geography and cartography space offers great promise in reducing the cost of mapping the Earth, as shown in figure 154. As the chart demonstrates, space photography can greatly reduce the number of photographs required to update our national series of topographic maps. In addition, it

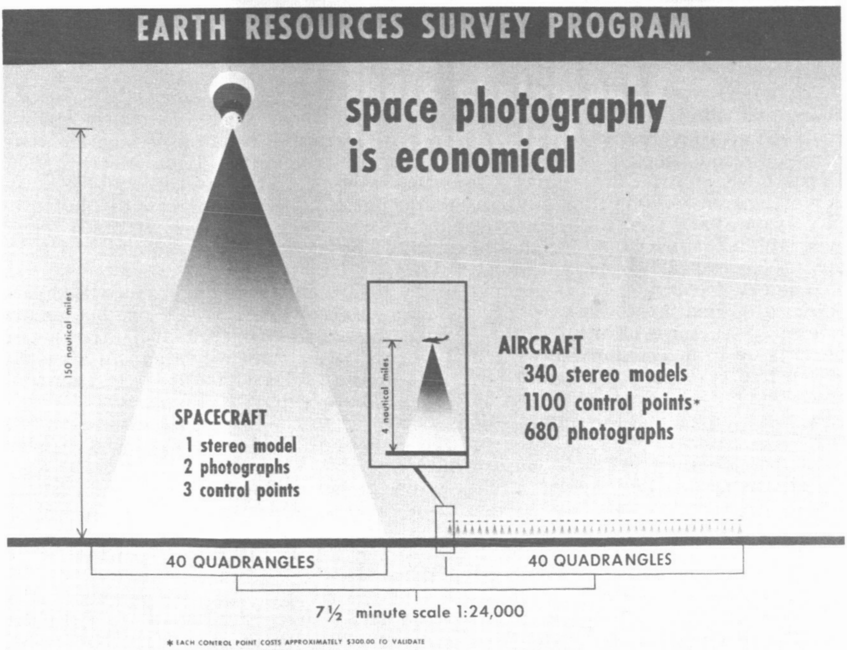


FIGURE 154

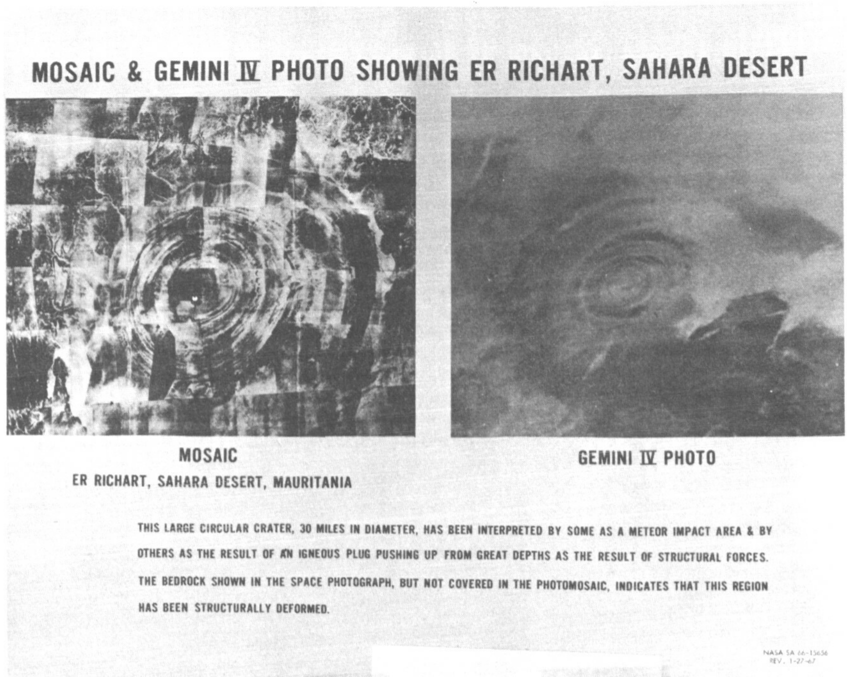


FIGURE 155

should be noted that the number of accurately located ground control points required to convert space photography to topographic base maps is more than three-hundred times less than with photographs acquired from aircraft. The Department of Interior estimates that the value of up-to-date topographic maps is worth nearly $700 million annually to our national economy. Synoptic photography from space also often provides us with a clearer picture of many large geographic features than is possible with a mosaic of photographs taken from aircraft as is clearly apparent in figure 155.

Imagery from space also permits us to study many remote areas which are potentially rich in mineral resources. Many of the world's major ore bodies are related to fractures (faults) in the Earth's crust. The view from space frequently permits us to detect and trace such fractures better than we can from airborne or surface surveys. Figure 156 shows one of the faults (fractures) to the right of the center which was detected by Gemini photography, while figure 157 shows how the position of fault intersections is related to the location of known major copper deposits in Arizona. Most of the copper ore bodies in this area are located near the intersection of major faults.

Satellites can also be of great value in gathering data through space photography which will help us determine arable land as well as soil which is not suitable for agriculture due to unfavorable salinity or other chemical constituents. While figure 158 is a photograph taken by an aircraft, it represents the usefulness of photographs taken from space. In this picture we have been able to determine that the areas of unhealthy cotton and bare soil have a much higher salinity than the areas where the cotton is healthy. Similar infrared photographs, such as figure 159, can show the onset of the insect disease in our forests, the diseased trees showing up differently on infrared film. While these films were taken from aircraft, we believe that appropriate surveys of food and forest areas can be made from space and that the data can be handled automatically by computers to distinguish the conditions of the various types of crops and soils.

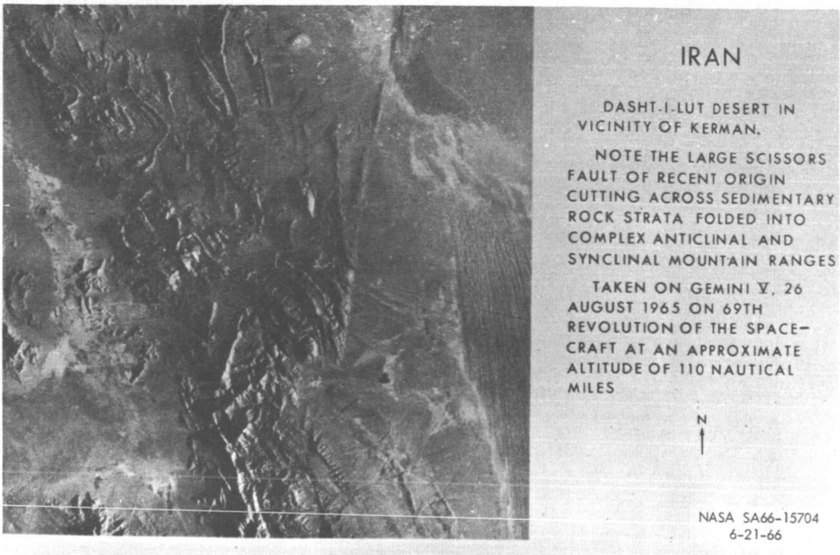


FIGURE 156

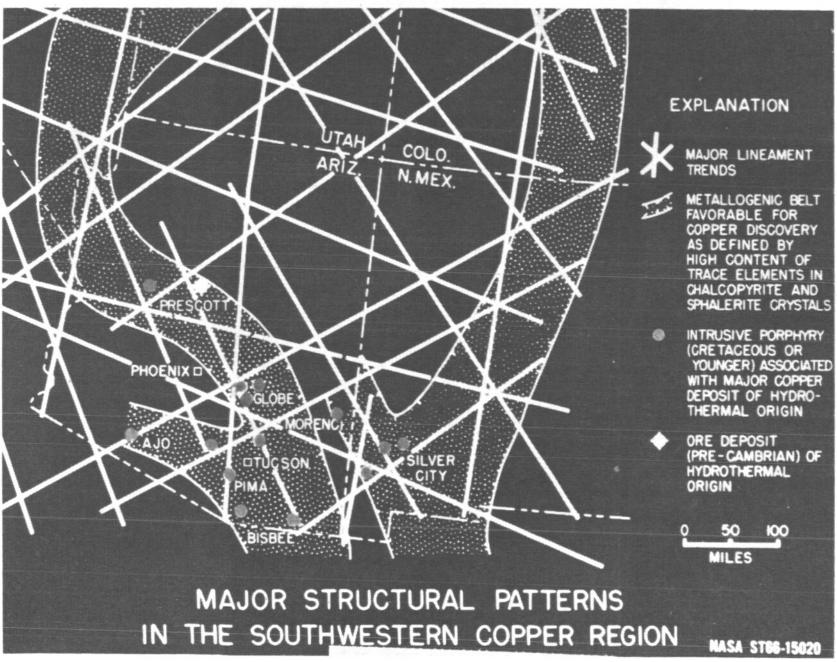


FIGURE 157

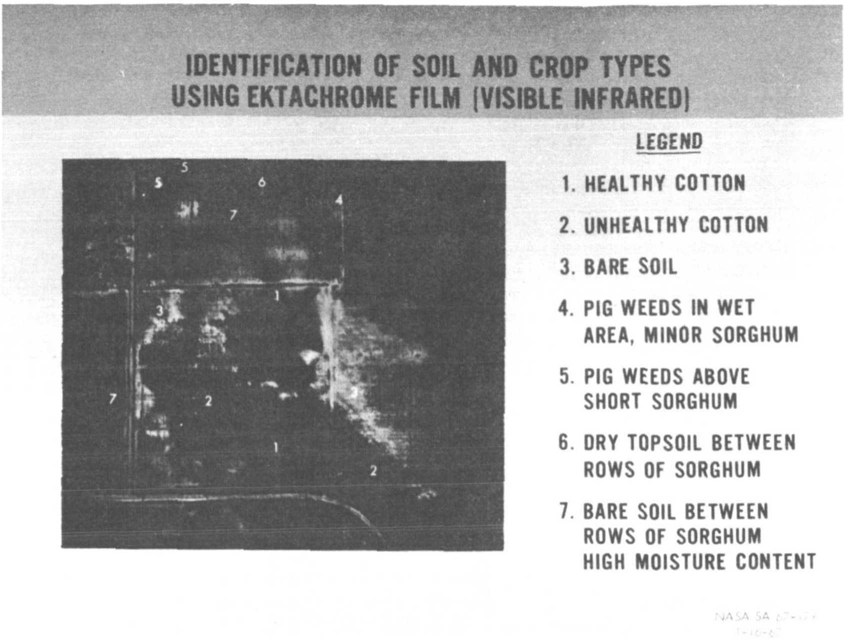


FIGURE 158

We can do a great deal from space toward surveying our fresh water situation. Figure 160 indicates that lake colors can be correlated with the biological, chemical, sediment, and pollutant content. We have also learned that infrared imagery can be utilized to locate fresh water which is escaping along our coast lines (fig. 161). It has been estimated that such water losses of this type may amount to about one-sixth of the total fresh water available to our ever-increasing population. After detecting such escape areas it is possible to save this water by locating suitable water wells inland from them. Using infrared techniques, we have also been able to locate areas of water which have been trapped by faults in the Earth's crust (fig. 162). The dark areas on this chart show the location of near surface water.

Glaciers are an important source of fresh water and their growth and decline (fig. 163) are very sensitive indicators of the available supply.

Satellites such as Nimbus have demonstrated their capability for monitoring the thermal characteristics and sea-state of the oceans which, because of their vast size and dynamic nature, are very difficult to map by any other means. Figure 164 shows that we are able to map the Gulf Stream by satellite. The Bureau of Commercial Fisheries has told us that there is a close correlation between fishery production and the thermal characteristics of the ocean and that they are very interested in having us develop more accurate spaceborne instruments for monitoring these thermal conditions, since this could significantly improve the efficiency of our fishing fleet.

This country today must purchase from foreign fishing fleets over half of the fish products consumed in the U.S. annually. The prospects of transforming fish into a high protein general purpose food which is currently being viewed as a potential partial solution to the world food shortage problem will demand an even more efficient world fishing industry. It should be noted that the Food and Drug Administration very recently approved the use of high protein fish flour for human consumption.

Imagery from space can also assist in mapping navigation routes in coastal and shoal water areas and in helping us to control and counteract silting in our major harbors and navigable rivers. Figure 165 shows the clarity with which

FIGURE 159

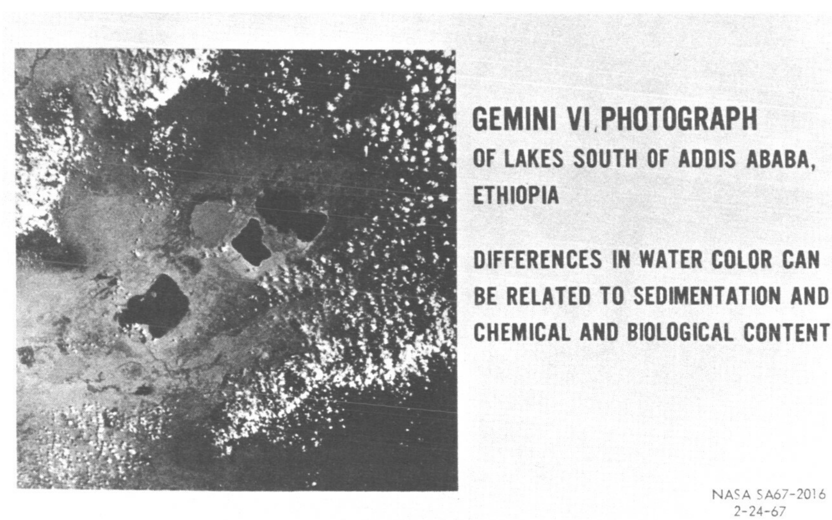


FIGURE 160

FIGURE 161

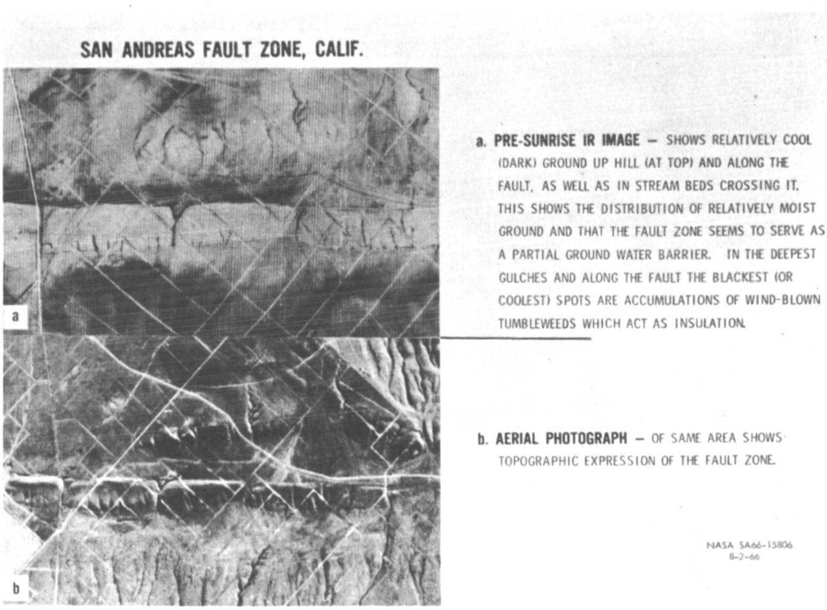


FIGURE 162

INFRARED IMAGE OF SOUTH CASCADE GLACIER AREA

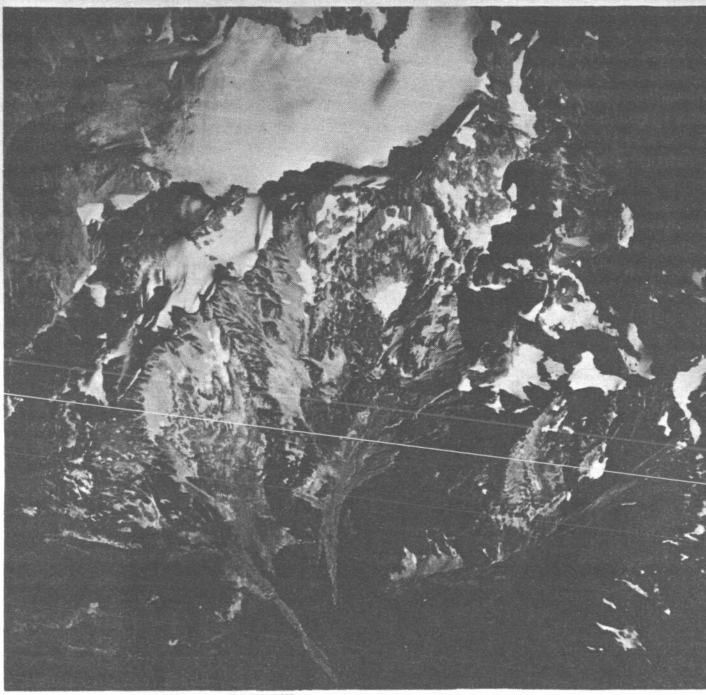


FIGURE 163

the bay shelf and sand bars show up in this imagery, and figure 166 shows the utility of space photography in charting shoal water areas. Ultimately, spaceborne instrumentation may permit observation of the sea-state and wave heights of our oceans.

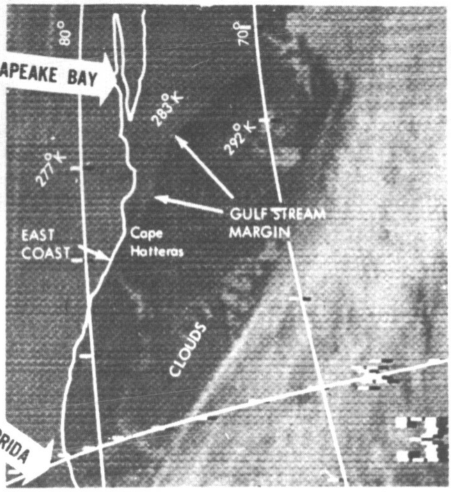
Although it will not be possible to acquire all of the needed Earth resources data by sensors located directly in the satellites, it is possible to supplement such data by locating surface instruments such as buoys, water gauges, strain gauges, and so forth, at strategically located positions on the surface of the Earth, as suggested in figure 167. These surface instruments could transmit the data to satellites which would relay the data to central data handling stations.

We are excited about the great potential of this Earth resources survey area, and we in NASA have been working with all the appropriate and interested government agencies, including the Departments of Agriculture, Commerce, and Interior, as well as many universities and research organizations, to make a truly national assessment of the potential of this area. It is our conclusion that the time is now right and urgent to bring specifically designed space experiments to bear upon the solution of the many pressing Earth resources problems which are being compounded by our population and industrial growths.

Space applications summer study

To assist us in our program planning and in evaluating the relative importance of pursuing these various goals, the National Academy of Sciences has agreed to sponsor a Summer Study to be held in two parts in the summers of 1967 and 1968. The purpose of the study is to bring to bear the best independent scien-

SAMPLE OF USEFUL EARTH RESOURCES DATA OBTAINED BY NIMBUS II



NIMBUS II HIGH RESOLUTION INFRARED IMAGERY CLEARLY DEPICTS THE GULF STREAM. TEMPERATURE VALUES WERE DETERMINED BY MICRO-DENSITOMETER.

NIMBUS IR IMAGERY CAN BE VERY USEFUL IN DETERMINING THE LOCATION, DISTRIBUTION, AND MOVEMENT OF THE MAJOR OCEAN WATER MASSES.

STUDIES OF THIS NATURE WILL BE OF GREAT VALUE TO OCEAN-OGRAPHERS, METEOROLOGISTS, AND TO THE WORLD'S FISHING AND SHIPPING INDUSTRIES.

NASA HQ SA67-15431

FIGURE 164

S

N

VIEW OF THE MOUTH OF THE COLORADO RIVER

TAKEN FROM GEMINI 4 IN JUNE 1965 WITH A HASSELBLAD 500C, ALTITUDE OF 110-120 N. MI. THE SONORA DESERT OF MEXICO OCCUPIES THE LOWER RIGHT HAND PART OF THE PHOTO.

NASA SM65-15543
7-6-65

FIGURE 165

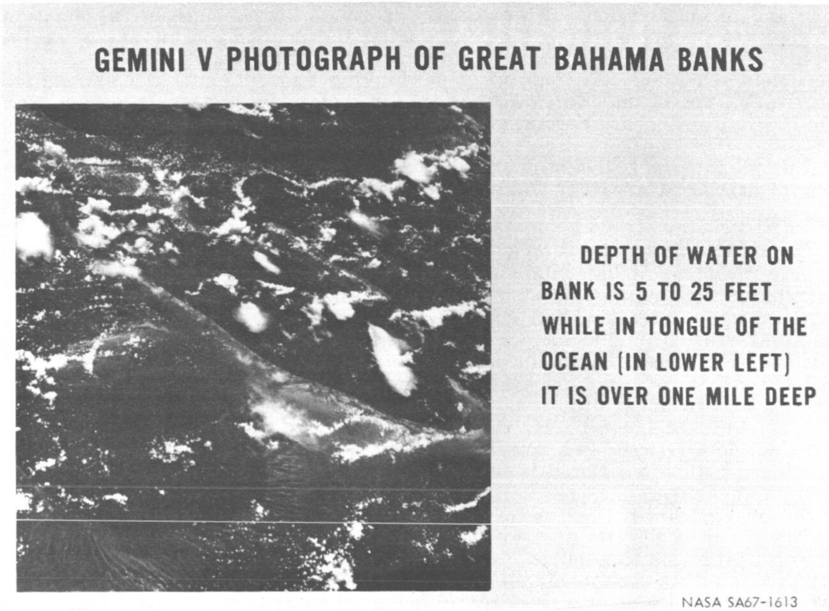


FIGURE 166

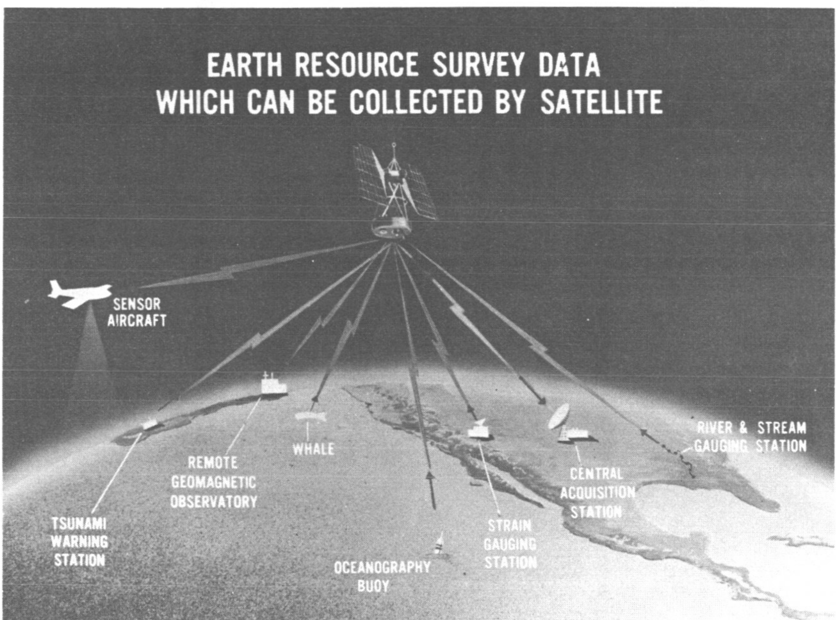


FIGURE 167

tific and technical talent in the country in reviewing the possible applications of space to the needs of mankind. To assist the Academy in planning for this Study, we are in the final stages of preparing a comprehensive basic resource document which outlines our program thinking and rational, and summarizes our work done to date, our efforts currently underway, and our program plans for the future. We are encouraging broad participation in this Summer Study to assure that the final output reflects the outlook and views of potential users and people knowledgeable on matters of broad policy and economic implications, as well as those of scientists and engineers.

Summary

In the foregoing discussion I have attempted to illustrate some of the more apparent and more immediate applications of space. The space applications that have been reduced to some operational practice such as communications, meteorology, navigation, and geodesy, and those that will be developed have had and will continue to have a rather substantive impact on our economy and our everyday lives. Communications satellites are already routinely providing reliable telephone communications on practically a global basis and we are having events of international significance brought into our living rooms through intercontinental television. A new industry has been established.

Meteorological satellites are today providing a major input to our daily weather prediction. Satellite utilization for navigation, traffic control and search, and rescue purposes will be an important factor in economic utilization of the air corridors and our use of the oceans.

The potential of satellites to distribute or broadcast news, educational and cultural programs to populations of entire nations or regions must be seriously studied, for there is probably no other single effort that could more directly contribute to the rate of progress of developing areas and to understanding among men.

The potential importance of being able to monitor and survey from space and consequently protect our natural and cultural resources must be neither under- nor over-estimated. The prudent and efficient utilization of the resources available to us on Earth is mandatory and urgent. The role that satellites can and should play must be developed with a sense of urgency.

Progress in the future, however, can be expected to proceed at a much more rapid pace than in the past; for the space tools of today are much more sophisticated than those of a few years ago. Launch vehicle capability and reliability have grown considerably. The establishment of a manned capability in space will permit more rapid development of required technology and instrumentation for subsequent transfer to automated operational systems of the next generation.

There is no question that the United States has been effective in and has been recognized for its role in the exploitation of space for the benefit of mankind. Many nations throughout the world now understand the potential economic return, both directly and in terms of the technical base developed by the U.S., in the pursuit of these very important and powerful uses of space.

It is because of the early start in the area of communications and meteorology that the U.S. enjoys this position today. It is because of the support of Congress in the early days of the space program that research and development programs were successfully executed, resulting in the new communications capability and in the beginning of the global understanding of the weather and our Earth itself that we enjoy today. Extension of these services and full development of the potential of space applications will surely have a profound and immediate effect on our everyday lives here on Earth.

CHAPTER III. BUDGET REQUEST FOR SPACE SCIENCE AND APPLICATIONS PROGRAM

I am particularly pleased to report to you this year on the outstanding progress which has been made in the scientific exploration of space and in the practical application of space flight to the benefit of man. Your Committee may justly take pride in these accomplishments, for, without your strong support, the United States would not now hold a position of strength in this important area. Such leadership must be held as well as earned. We must continue to press forward with this vital program. The opportunities which lie ahead are even more exciting and important than those already realized.

Mission record

The program which we propose this year is solidly based on a history of outstanding accomplishments in space about the Earth, the Moon, and the planets. The 1966 series of dramatic successes with second and third generation automated spacecraft demonstrated striking advances in the utility, durability, versatility, and effectiveness of this equipment. The flights of Nimbus II, OGO III, Surveyor I, Orbiters I and II, and the Applications Technology Satellite I were highlights. The scientific and practical significance of the results of this program have been described in the preceding chapters.

Those of you who worked with us during the early years of the space program will particularly appreciate the mission record for Calendar Years 1965 and 1966 (fig. 168, fig. 169, and fig. 170). Twenty-three of the 28 NASA science and applications missions were successful. In addition, all 5 non-NASA-developed payloads and the joint U.S./Canadian Alouette, for which we held vehicle responsibility, were successfully launched. Further the Atlas Centaur development program was successfully completed and Centaur was used to launch Surveyors I and II.

Level of activity

The Space Science and Applications Program is at its peak level of activity—and accomplishment. All but two of the many automated spacecraft systems begun since the start of the space program have achieved a fully developed status. Many have been or will soon be phased out, having successfully achieved their objectives. The time has now come to replace those objectives set in the early 1960's with equally imaginative and challenging goals for the future. There are many important opportunities from which to choose.

Because of budgetary constraints, it was necessary to operate the Space Science and Applications Program at $607.1 million in Fiscal Year 1967, as summarized below and in fig. 171.

Space Science and Applications Program	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Physics and astronomy	$142,753,000	$129,800,000	$147,500,000
Lunar and planetary exploration	204,300,000	169,400,000	142,000,000
Voyager	17,096,700	10,450,000	71,500,000
Sustaining university program	46,000,000	31,000,000	20,000,000
Launch vehicle development	57,790,000	31,200,000	
Launch vehicle procurement	178,700,000	122,400,000	165,100,000
Bioscience	34,400,000	41,550,000	44,300,000
Space applications	78,053,000	71,300,000	104,200,000
Total	759,092,700	607,100,000	694,600,000

We deferred not only new starts but also followon buys of developed equipment. The Advanced Orbiting Solar Observatory was cancelled. Surveyor, Orbiter, and probably the Orbiting Geophysical Observatory (OGO) are being phased out earlier than originally planned. The result of these actions has been to reduce flight activity in the present program to about 30% of the current level by 1970, with a corresponding serious reduction in anticipated results. The President's Fiscal Year 1968 budget will enable us to reverse this trend and will give us an opportunity to hold the leadership in space we have so laboriously won. We feel that the outstanding results of the program to date fully justify your continued strong support.

In Fiscal Year 1968, an increase in the budget for the Office of Space Science and Applications (OSSA) is proposed. This budget of $694.6 million is nevertheless below those of Fiscal Years 1964, 1965, or 1966 for this program. It will provide a sufficient level of activity to insure capitalizing in the 1970's on some of the opportunities which lie ahead.

The importance of this budget to the flight program is illustrated in figure 89. This chart shows the flight activity in the Space Science and Applications Program since 1960. The number of launched or scheduled missions is seen to decrease rapidly to zero in the early 1970's. Additional missions included in the Fiscal Year 1968 budget are shown to fall off rapidly also. Because of the typical three-year procurement lead time for all but the simplest spacecraft, it is inevitable that this downward trend continue until about 1971. The course of the

SPACE SCIENCE AND APPLICATIONS

MISSION RECORD CY 1965–1966

SCIENTIFIC SATELLITES

CY 1965		CY 1966	
EXPLORER XXVII	SUCCESS	EXPLORER XXXII	SUCCESS
EXPLORER XXVIII	SUCCESS	EXPLORER XXXIII	SUCCESS
EXPLORER XXIX	SUCCESS	ORBITING ASTRONOMICAL OBSERVATORY I	FAILURE
EXPLORER XXXI	SUCCESS	ORBITING GEOPHYSICAL OBSERVATORY III	SUCCESS
OSO II	SUCCESS	BIOSATELLITE I	FAILURE
OSO C	VEHICLE FAILURE		
OGO II	FAILURE		
ALOUETTE II	SUCCESS		

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1-5-67

FIGURE 168

SPACE SCIENCE AND APPLICATIONS

MISSION RECORD CY 1965–1966

DEEP SPACE PROBES

CY 1965		CY 1966	
RANGER VIII	SUCCESS	PIONEER VII	SUCCESS
RANGER IX	SUCCESS	SURVEYOR I	SUCCESS
PIONEER VI	SUCCESS	SURVEYOR II	FAILURE
		LUNAR ORBITER I	SUCCESS
		LUNAR ORBITER II	SUCCESS

LAUNCH VEHICLE DEVELOPMENT

CY 1965		CY 1966	
CENTAUR (AC-5)	FAILURE	CENTAUR (AC-8)	FAILURE
CENTAUR (AC-6)	SUCCESS	CENTAUR (AC-9)	SUCCESS
SCOUT EVALUATION (VEHICLE A)	SUCCESS		

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1-5-67

FIGURE 169

SPACE SCIENCE AND APPLICATIONS
MISSION RECORD CY 1965–1966

CY 1965 | SPACE APPLICATIONS | **CY 1966**

CY 1965		CY 1966	
TIROS IX	SUCCESS	ESSA I	SUCCESS
TIROS X (OT-1)	SUCCESS	ESSA II	SUCCESS
		ESSA III	SUCCESS
		NIMBUS II	SUCCESS
		PAGEOS	SUCCESS
		APPLICATIONS TECHNOLOGY SATELLITE I	SUCCESS

NON-NASA MISSIONS

CY 1965		CY 1966	
INTELSAT I (EARLY BIRD I)	LAUNCH SUCCESS	INTELSAT II	LAUNCH SUCCESS
EXPLORER XXX	LAUNCH SUCCESS	OV-3	LAUNCH SUCCESS
FRENCH I	LAUNCH SUCCESS		

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1-5-67

FIGURE 170

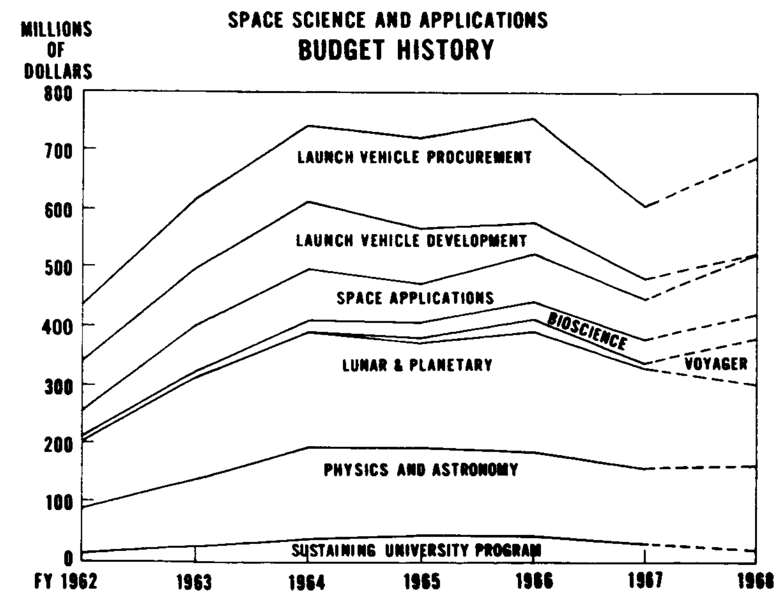

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FIGURE 171

program beyond that date will depend on Fiscal Year 1969 and later funding, but it is our intention and conviction that the space science and applications accomplishments of the 1970's will be even more productive than those of the 1960's.

Future opportunities

New mission activity which is covered in the Fiscal Year 1968 budget is shown in figure 90, along with the funding required in that year. Each of these projects will be discussed later. By way of introduction, however: *Voyager* is a major program of great importance and far-reaching significance. Because of its importance, specific authorization is being requested. It is designed to explore Mars and Venus with the combined orbiter-plus-lander technique used so successfully on the Moon. The first flight would be a Mars mission in 1973. Fiscal Year 1968 funds would cover the detail design (Phase C) of the Voyager systems. See figure 99 which further illustrates the Voyager design and development philosophy. The spacecraft bus will fly to the planet, inject itself and the landing capsule into planetary orbit, and continue to function in orbit as a scientific observatory. The technology for this system evolves directly from Mariner, Orbiter, and OGO. The 5000 to 7000 pound entry capsule and landing system evolve directly from Surveyor and Apollo technology. This system includes an automated surface laboratory weighing from 860 to 1500 pounds. This laboratory will conduct physical, chemical, and biological experiments under the direction of a team of scientists on Earth. Two complete systems will be launched with a single Saturn V launch vehicle.

Mariner Mars '71 is a project to extend the use of the Mariner Mars '69 design by including an atmospheric entry probe which would not survive impact. It would directly measure and confirm key atmospheric properties of Mars in advance of the first Voyager mission, and permit adjusting the Voyager mission profile and experiments for optimum performance. Development of the sterilized probe would constitute an important technological forerunner to the more complex Voyager effort. The Mariner system would also be adaptable to Venus flights beginning in 1972. Fiscal Year 1968 funds would permit Phase C detail design for the Mars mission in 1971.

As a clever approach to their solar studies, the Massachusetts Institute of Technology has designed the *Sunblazer* deep space probe. This relatively simple system of solar satellites would be launched to escape velocity by Scout vehicles. Immediate initiation of flight hardware would lead to flights in 1968.

Preliminary design (Phase B) is proposed for a *Voice Broadcast Satellite* with Fiscal Year 1968 funds. This system could broadcast high quality FM voice material directly into the home over continental areas. This type of satellite could be a particular boon to developing nations with inadequate broadcast and distribution systems of their own. Ultimately, broadcast satellites will replace conventional radio and television distribution systems with improvement in quality and reduction in cost. If followed up with Phase C funds in Fiscal Year 1969, such a system could fly in 1972.

A new *Applications Technology Satellite* configuration is proposed to develop the technology of high gain, precisely steerable antennas in synchronous Earth orbit. This technology will be applicable to advanced radio and television broadcast satellites, navigation and traffic control satellites, data collection and transmission satellites, and other practical uses. The narrow beam parabolic antenna planned for this satellite minimizes spacecraft power requirements and ground station complexity. Fiscal Year 1968 funds will allow completion of preliminary design and initiation of a Phase C detail design. First flight would be in 1971.

The *Nimbus* followon effort reflects our conclusion that an improved version of the current Nimbus weather satellite is the best approach to continuing R&D in satellite meteorology. The need is definitely for heavier instruments, increased power, and long lifetimes. This is particularly true during the research period when various instruments are being tested and compared for suitability for operational use.

Program plans and progress

I would like now to direct your attention to the content of the various subdivisions of the OSSA program, and to the considerable progress which has been made during 1966.

Physics and astronomy programs

Simply stated, these programs are directed toward fundamental scientific studies of the Earth, Sun, and stars. The physics of space around the Earth en-

compasses the atmosphere, ionosphere, and magnetosphere. Solar physics includes the fundamental processes taking place within the Sun, its atmosphere, and its radiations. In addition, we are concerned with the effect of solar emanations upon the Earth itself. Our work in space astronomy is largely complementary to ground-based astronomy in that it concentrates on observing the celestial sphere in such wavelengths as long-wave radio, ultraviolet, X-rays, and gamma rays, which are not observable from the Earth's surface. From these observations could come revolutionary new concepts in our understanding of the universe.

Mastery of these various areas of space science is necessary before we can truly say with confidence that we understand this newly-accessible medium through which we fly.

To conduct this research, it is necessary to utilize sounding rockets, satellites, and deep space probes, in combination with a strong program of Earth-based laboratory research as summarized below, see also figure 91.

	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Supporting research and technology/advanced studies	$20,594,000	$19,900,000	$19,900,000
Solar observatories	19,052,000	9,800,000	11,900,000
Astronomical observatories	22,300,000	27,700,000	40,600,000
Geophysical observatories	28,215,000	24,000,000	20,000,000
Pioneer	12,700,000	7,200,000	7,500,000
Explorers	18,592,000	19,200,000	21,600,000
Sounding rockets	19,300,000	20,000,000	22,000,000
Sunblazer			2,000,000
Data analysis	2,000,000	2,000,000	2,000,000
Total	142,753,000	129,800,000	147,500,000

The Supporting Research and Technology (SR&T) Program, which is planned to continue at the 1967 level, funds the work of the scientists in their laboratories evolving new concepts, preparing new experiments for possible space flight, or analyzing data from past flights. Frequently, before a new experiment is considered for inclusion on a satellite or deep space probe, it is first flown in a sounding rocket.

The Sounding Rocket Program serves the dual function of flight qualifying new experiments and of conducting basic research in that region of the atmosphere and ionosphere not accessible to balloons or satellites. A slight increase in sounding rocket funding is required because of the increasing complexity of instrumentation and the need for larger rockets.

The Explorer and International satellites continue as versatile and effective means of exploring space in the vicinity of the Earth with a wide diversity of objectives and orbits. In 1966 we successfully launched Explorer XXXII to probe the upper atmosphere, and Explorer XXXIII to monitor the interplanetary medium outside of the magnetosphere as well as to study the wake of the Earth, which has now been detected in the solar wind as far away as 4 million miles. A slight increase in the funds for Explorers is required as we extend satellite observations into the fields of X-ray astronomy and radio astronomy.

Initial results from Pioneer VI provided new insight into the propagation of solar cosmic rays and the temperature of the solar wind. Pioneer VII was also placed in orbit about the Sun in 1966 to monitor the interplanetary field. These two new Pioneers, teamed with Explorer XXXIII and Mariner IV, are now providing coverage of the propagation of solar disturbances at points widely distributed around the Sun. This program will continue at its present level throughout solar "maximum."

With the launch of the Orbiting Solar Observatories (OSO) D and E, study of processes taking place within the Sun will continue in 1967, to be followed by three more OSO's through solar maximum in 1969. Funding requirements are up slightly from 1967 as we enter this period of increased activity. The relatively continuous monitoring of the Sun with the OSO spacecraft will be supplemented by the detailed observations of Apollo Telescope Mount (ATM).

Funding requirements for Orbiting Geophysical Observatories (OGO) continue to decrease as the program approaches possible phaseover to a simplified version for cost reduction. The OGO's, which have been much more successful

than their official record indicates, provide a means of simultaneously carrying as many as 25 well-integrated experiments into the magnetosphere, or alternatively into the upper atmosphere. Simultaneous measurements of this type may prove to be the only way to unravel some of the more subtle and fundamental secrets of these environments.

The Orbiting Astronomical Observatory (OAO) continues as our most complex spacecraft and our most difficult undertaking among the orbiting observatories. Many believe it to be one of the most important projects in the space program. It is an essential stepping stone in developing the capability to conduct astronomical observations from space. The technology of continuous precision pointing under semi-automated direction from Earth-based astronomers over long periods of time appears desirable for still larger observatories of the future. The forthcoming experience with the ATM solar observations from manned spacecraft will further define the most effective approach to orbital astronomy for the future.

The OAO series had its first flight in 1966, one which ended in failure. Working closely with the Goddard Space Flight Center and its contractor, Grumman Aircraft Company, we conducted a number of investigations of this failure and the OAO system. The results of these reviews have been released publicly. In summary, we found that the probable direct and immediate cause of the loss of the OAO–1 was a failure in the Battery Charge and Sequence Controller that appears to have resulted in overcharging, overheating, and eventual failure of a battery pack and the power system. Further, it is believed that the major disruption to the operation of the OAO probably was caused by arcing in the star trackers. Advantage is being taken of the time required to rectify the failure areas to incorporate other improvements to increase the probability of success on the second flight, which has been delayed until 1968. The budget for OAO is up in Fiscal Year 1968, and accounts for $12.9 million of the $17.7 million increase in the Physics and Astronomy Program budget. However, the actual accrued costs for Fiscal Year 1968 will remain quite close to those in Fiscal Year 1967, which were higher than the budgeted amount due to carryover of prior year funds.

The last budget item to be discussed here is the Sunblazer, which I introduced earlier. At this point, I would like to mention there is available for the Committee's perusal a pamphlet providing a more detailed description of the Sunblazer program. This relatively inexpensive family of small Scout-launched solar probes constitute an important step in our exploration of the Sun as well as an effort to capitalize on small probe techniques for deep space exploration.

Some of the major accomplishments of the Physics and Astronomy Program are summarized. Figure 172 shows the relative orientations of the two highly eccentric orbits of OGO I and OGO III which were designed to study the magnetosphere. As the Earth rotates about the Sun, the magnetosphere rotates with respect to these orbits and is thus surveyed in great detail. The orbital plane of OGO II, which was placed in a low nearly-polar orbit to investigate the interface between the atmosphere and magnetosphere, is also shown. OGO III was the only official success since it was the only OGO to maintain 3-axis attitude stabilization. However, OGO I has continued effective operation since September 1964. The OGO's have yielded more data than all other geophysical satellites combined. Over 100 publications and reports at scientific meetings have presented the important results of the OGO investigations. Recently all three OGO's were in simultaneous operation providing unprecedented coverage.

Figure 173 summarizes some of the scientific highlights in the Physics and Astronomy Program in 1966. These important findings in the vast new laboratory of outer space are typical of the steady returns to science which have been forthcoming since the start of the space program. Their long-range impact on the evolution of science at home and abroad will be felt for years to come.

Lunar and planetary programs

The objective of these programs is the exploration of the Moon, the planets and their moons, and the asteroids and comets which make up our solar system. From these explorations, we are rapidly coming to understand our solar system much better, and we hope to unravel many of its mysteries. Such knowledge must include the history of biological evolution in the solar system, in which Mars is currently considered the most probable abode for extraterrestrial life.

The fact that we are now technologically ready to undertake exploration of the planets with automated spacecraft is reflected in the distribution of funds

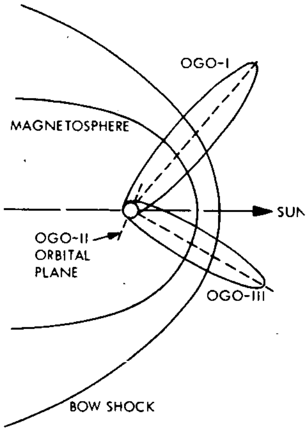
ORBITING GEOPHYSICAL OBSERVATORIES

OGO-I (SEPT 1964)

- CONTINUOUS EFFECTIVE OPERATION
- PROVIDED DETAILED DEFINITION OF MAGNETOSPHERE AND BOUNDARY CHARACTERISTICS
- CORRELATIONS WITH IMP, PIONEER, MARINER

OGO-II (OCT 1965)

- OPERATING
- FIRST GLOBAL WORLD MAGNETIC SURVEY
- DETECTED NEW LOW FREQUENCY RADIOWAVE PHENOMENA



OGO-III (JUNE 1966)

- OPERATING
- 46 DAYS OF CONTINUOUS ACTIVE STABILIZATION
- IMPORTANT LOW ENERGY ELECTRON MEASUREMENTS
- OBSERVED FOUR MAJOR SOLAR FLARES AUGUST-DECEMBER 1966
- CORRELATIVE MEASUREMENTS (46 EXPERIMENTS) FOR 2 WEEKS WITH OGO I AND OGO II.

NASA S67-609
1-5-67

FIGURE 172

PHYSICS AND ASTRONOMY

SCIENTIFIC HIGHLIGHTS 1966

1. BRIGHTEST CELESTIAL X-RAY SOURCE DISCOVERED TO BE REMNANT OF AN OLD NOVA (EXPLODED STAR).
2. PROVED TECHNIQUE OF BARIUM RELEASE OUTSIDE EARTH'S ATMOSPHERE, AND FIRST DETECTED ELECTRIC FIELDS IN SPACE.
3. DISCOVERY OF PREDICTED HELIUM "WHISTLER" SIGNALS IN SPACE, PERMITTED NEW, SENSITIVE MEASUREMENT OF HELIUM COMPOSITION IN UPPER ATMOSPHERE (ALOUETTE II).
4. DISCOVERY OF ANOMALOUSLY LOW AND FLUCTUATING IONIZATION HIGH ABOVE EARTH'S POLAR ZONE.
5. FIRST ACTUAL MEASUREMENT OF ION WAKE OF A SPACECRAFT (GEMINI 10, 11) MOVING THROUGH THE IONOSPHERE.
6. INTENSIVE OBSERVATION OF SUN'S CORONA DURING INCIPIENT NEW SOLAR CYCLE, USING A TOTAL ECLIPSE, AND SOUNDING ROCKETS CARRYING HIGH RESOLUTION X-RAY AND UV TELESCOPES.
7. PIONEER VII PROVIDED CLEAR EVIDENCE THE EARTH'S GEOMAGNETIC WAKE EXTENDS AT LEAST FOUR MILLION MILES IN SPACE.
8. DISCOVERY OF ENERGETIC ELECTRONS ASSOCIATED WITH SOLAR FLARES (MARINER IV).
9. DISCOVERY OF NEW MAGNETOSPHERIC OSCILLATORY RESPONSES TO INTERPLANETARY STORMS (IMP, OGO).

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FIGURE 173

in the Fiscal Year 1968 budget for lunar and planetary exploration as summarized below, see also figure 92.

Lunar and Planetary Exploration	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Supporting research and technology/advanced studies	$23,000,000	$20,900,000	$20,900,000
Surveyor	104,634,000	84,500,000	42,200,000
Lunar orbiter	58,081,000	28,800,000	10,000,000
Mariner	17,585,000	35,200,000	68,900,000
Ranger	1,000,000		
Total	204,300,000	169,400,000	142,000,000

Supporting Research and Technology (SR&T), which is held at the Fiscal Year 1967 level, undergirds the future development of the program by providing new scientific experiments and required technology in direct support of lunar and planetary missions. Past investment in this effort has laid the groundwork for the planetary exploration which we now propose.

We have achieved sufficient success early in the Surveyor and Lunar Orbiter programs to feel confident that the initial needs of the Apollo program can be met with the seven Surveyors and five Orbiters now under contract. We are even hoping that at least one of the Orbiters can be utilized exclusively for scientific observations in regions other than the Apollo landing zone. Accordingly, the followon procurements of those spacecraft will be indefinitely deferred in order to make funds available for planetary exploration. Should the sum total of knowledge about the Moon gained from Ranger, Surveyor, Orbiter, Apollo—and Luna—indicate the desirability of extensive lunar exploration throughout the 1970's, automated lunar spacecraft would be reinstated in the program as required to supplement manned missions.

Before discussing the planetary portion of the program, let me take a moment to summarize the outstanding results of the lunar program during 1966. The successful landing of Surveyor I within a few miles of its target in Oceanus Procellarum was a highlight of the year. From lift-off at Cape Kennedy through its transmission of over 11,000 pictures and its resurrection on the second lunar day, the mission of Surveyor I was perfect. See figure 93 which shows some samples of Surveyor's photography. The terrain was found to be similar to the mare areas previously observed by the Rangers and by Luna IX in that it was gently undulating and pocked by craters of all sizes. Rocks similar to those first observed by Luna IX may be seen nearby and one of these is shown enlarged in figure 93. An important new finding was the presence of large rock fields in the distance, apparently associated with ejecta from large craters. A magnified view through Surveyor's zoom lens is also shown in the chart. These individual rocks are as large as several yards across. Lunar Orbiter photography has shown such rock piles to be non-uniformly distributed over the lunar surface.

By viewing the 1- to 2-inch depression made by Surveyor's footpads, and by analyzing the accelerations and strain-gauge measurements during landing, it has been possible to tell a good deal about the properties of the surface. The surface appears to consist of loosely-constituted and moderately-cohesive particulate matter of generally small size. The Surveyor exerted from 6 to 10 pounds-per-square-inch force on the surface. The surface bearing strength is thus at least this great and more likely higher. The consistency of the surface material seems much like dried silt; one could scoop it up with his hands, and would sink in slightly when walking across it. Luna XIII subsequently confirmed these determinations of surface properties.

The first two Lunar Orbiter missions were also extremely effective. Orbiters I and II photographed 28,000 square miles of 22 primary Apollo sites at a resolution of about 25 feet, as shown in figure 174. In addition, four thousand square miles covering 13 of the 22 primary sites were photographed at a high resolution of about 3 feet by Orbiter II. Lunar Orbiter III has just recently successfully completed photographing an additional 12 potential Apollo sites. See figure 94 which illustrates the effectiveness of this photography. The left-hand photograph shows an area of 4.7 x 6.3 miles at the 25-foot resolution. These photos are taken in stereo pairs and make possible a rapid evaluation of large areas and the elimination of obviously poor terrain. The right-hand photograph is a 2300 x 3100 foot portion

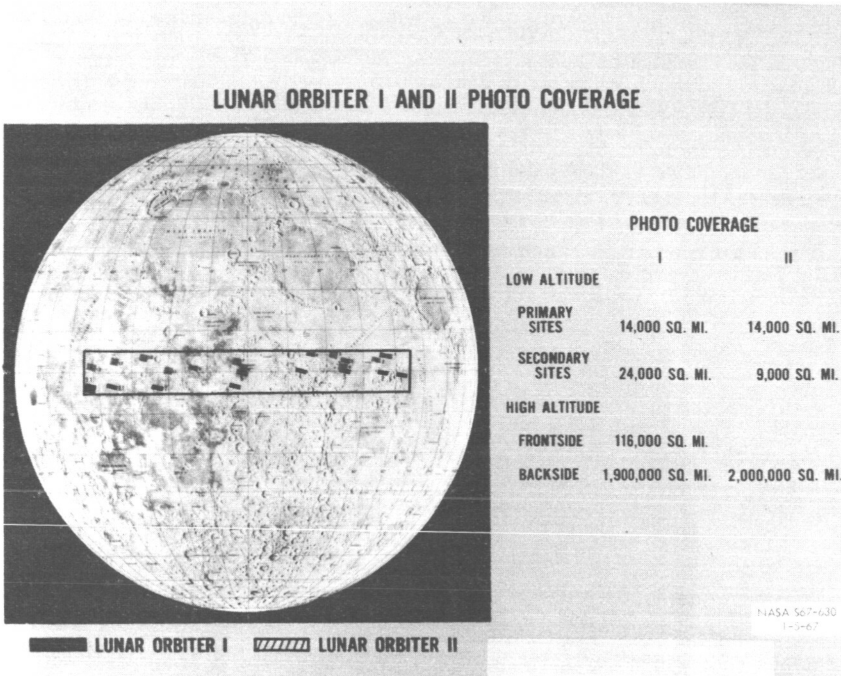

Figure 174

of the area in the photograph at the left as observed with the high resolution camera. Objects three feet or smaller are clearly discernible in the original negatives.

A detailed recounting of the many scientific findings in this wealth of data is not possible herein. The roughness of the surface was found to be highly variable, even within the maria. The dark maria are the smoothest regions. Numerous small sites have been found which appear useable for landing with the Apollo LEM spacecraft. However, none have been found which fully meet the initial Apollo site specifications for smoothness, slopes, and radar approach topography. The best landing sites found to date are from 10% to 15% cratered and typically contain about 10,000 hazardous craters within the Apollo 16-square-mile dispersion ellipses. Piloting at touchdown will thus be important in the LEM landing. Mass wasting and slumping of material in response to gravity appears to be an important process in modifying the surface. Importantly, the surface shows evidence of volcanic activity. There seems little doubt that the Moon will be a highly interesting object of exploration.

See figure 97 for an oblique photograph of the crater Marius and its "hills," made with one of the Orbiter's film frames which must be exposed periodically during long intervals between primary site photography. About 150,000 square miles of additional frontside coverage were obtained in this manner, as well as about 4 million square miles of high quality lunar farside photography.

From a technological point of view, the control of the Orbiter in its flight about the Moon was extremely precise. The spacecraft responded to thousands of commands and executed hundreds of attitude changes. Apolune and perilune were controlled to within a mile. Cameras were pointed with high accuracy at the lunar sites. Orbiter and Surveyor demonstrated much of the technology required for Voyager, which will extend the orbiter/lander exploration mode to Mars and Venus.

The reduction of $61.1 million in lunar exploration, because of an early phase-out of Surveyor and Orbiter, is offset by an increase in Fiscal Year 1968 of $33.7 million in the Mariner program to probe Mars and Venus, and $61 million in the Voyager program leading to automated surface exploration of these planets.

During 1966, excellent progress has been made in preparing for the Mariner flight to Venus in June of 1967, and the two flights to Mars in 1969. In addition, studies have been completed on how to adapt the 1969 spacecraft to carry atmospheric probes to Mars and Venus in 1971 and 1972 respectively. Adapting Mariner to carry a several-hundred-pound probe appears practicable and highly desirable in its own right, as well as an asset to planning the final details of the Voyager mission. Accordingly, $10.1 million are included to initiate this development. There is available to the Committee a summary description of the most recent additions to the Mariner program.

Voyager program

The Voyager program, summarized in Table 4 and Chart S67–1615 constitutes what many consider to be the most important undertaking in deep space exploration since Project Apollo was authorized in 1961.

	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Spacecraft system	$8,191,000	$1,300,000	$21,400,000
Capsule bus system	7,622,000	8,100,000	21,600,000
Surface laboratory system			24,000,000
Voyager biological laboratory	1,000,000	450,000	2,500,000
Launch vehicle system	210,000	500,000	1,500,000
Mission operations	74,000	100,000	500,000
Total	17,097,000	10,450,000	71,500,000

Voyager represents a decision to investigate our nearest neighbors, Mars and Venus, with automated spacecraft capable of surveying them from orbit and of carrying out scientific investigations on the planetary surfaces. The approach parallels that which we have used so successfully on the Moon, but with a much greater complement of instrumentation to answer as many of the fascinating questions about these planets as possible. What do they look like? What are they made of? What makes up their atmosphere? What is their weather like? What is their internal structure? How were they formed and what has been their evolution? How do they relate to the Earth and other planets? Is life present? If not, was it ever present or might life be sustained there in the future?

These and other questions have led the Space Science Board to say:

"We recommend planetary exploration as the most rewarding scientific objective for the 1970-1985 period."

A recommendation of the Exobiology Study conducted for the Space Science Board stated:

"The biological exploration of Mars is a scientific undertaking of the greatest validity and significance. Its realization will be a milestone in the history of human achievement. Its importance and the consequences for biology justify the highest priority among all scientific objectives in space—indeed, in the space program as a whole."

Progress in the Voyager program during 1966 has been good. We have completed preliminary design studies of the entry and landing system and of the surface laboratory, and have recently invited aerospace companies to bid on Phase B or design definition of these systems which should confirm and refine the approach which we have selected. This approach involves the use of a radar-controlled rocket landing system of the Surveyor/Apollo type, after atmospheric entry behind a heat shield. Upon completion of this work, the entry and landing system design progress should have "caught up" with the orbiting spacecraft design which was begun nearly two years ago. Detail design of all systems (Phase C) would then be undertaken later this fiscal year and Phase D hardware procurement would be initiated in Fiscal Year 1969, after another round of reviews and approvals.

The attention of the Committee is called to a summary description of the Voyager program which I think you will find informative. See figure 98.

See figure 100 which presents the management structure for Voyager. Program direction will reside in the Office of Space Science and Applications, NASA Headquarters. Management of the several Voyager systems will involve NASA field

centers and the Jet Propulsion Laboratory. JPL, headed by Dr. William Pickering, will manage the surface laboratory system, using a systems contractor, as well as the tracking and data acquisition system and the space flight operations system. The Langley Research Center, headed by Dr. Floyd Thompson, will manage the entry capsule and landing system, also using a systems contractor. The Marshall Space Fight Center, under the direction of Dr. Wernher von Braun, will manage the orbiting spacecraft development and the retropropulsion system, again with the aid of a contractor, and will integrate the capsule assembly into the spacecraft bus. Marshall will also manage the Saturn V and the integration of the two complete spacecraft assemblies onto the Saturn.

Thus, Voyager will not only make maximum use of existing hardware and technology developed by the space program, but will also make maximum use of the considerable capabilities of the teams of managers, engineers, and scientists which have been developed at these outstanding laboratories.

Space applications programs

The objective of this portion of our program is to continue to develop practical applications of space flight so as to maximize the return on our national investment. This program has been highly successful in the past. From the TIROS and Nimbus programs has come an operational meteorological satellite system under the direction of the Environmental Science Services Administration (ESSA) with NASA delivering the spacecraft in orbit. From the Syncom program has come an operational communications satellite system under the management of the Communications Satellite Corporation. The Air Force now has its own communications system in a nearly synchronous orbit. The U.S. Navy navigational satellite is operational with the fleet. The Geodetic Earth Orbiting Satellite (GEOS) and Passive Geodetic Earth Orbiting Satellite (Pageos) are serving a combined scientific and operational function.

The proposed program for Space Applications for Fiscal Year 1968 is summarized below, see also figure 101.

	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Supporting research and technology	$10,839,000	$11,630,000	$16,600,000
TIROS/TOS improvements	2,500,000	3,100,000	7,500,000
Nimbus:			
Nimbus A-D	22,560,000	23,400,000	29,500,000
Nimbus E-F			5,000,000
Meteorological soundings	2,730,000	3,000,000	3,000,000
French satellite (FR-2)		100,000	100,000
Applications technology satellites:			
ATS A-E	34,431,000	28,470,000	19,800,000
ATS F and G			15,700,000
Geodetic satellites (A-E)	4,993,000	1,600,000	4,700,000
Voice broadcast satellite			2,300,000
Total	78,053,000	71,300,000	104,200,000

Opportunities for important new practical applications of satellites appear very great in all of the areas I have mentioned. One additional area of promise is that of Earth resources. In Fiscal Year 1967, research in this area is being funded by manned space science funds. In Fiscal Year 1968, it is being carried in SR&T in space applications and accounts for all of the increase there. Earth resources observations from orbit would include geological and oceanographic surveys; searching for mineral and oil deposits; monitoring of water resources including lakes, streams, and snow fields; and monitoring of both water and air pollution. The orbital observation of crops would aid in global food management and in detection of crop disease. Similarly, satellite observations can assist in forestry. Research needs to be conducted not only on how best to make these surveys, but also how best to use the data. The various agencies of the government concerned with these matters are now jointly studying the problems. Figure 175 illustrates with an aircraft photograph the potential of color photography in appropriate wavelengths for such surveys.

Three satellites were successfuly launched for the Environmental Science Services Administration in 1966. In 1968 the ESSA operational meteorological satellite system will receive the services of an entirely new satellite, which we

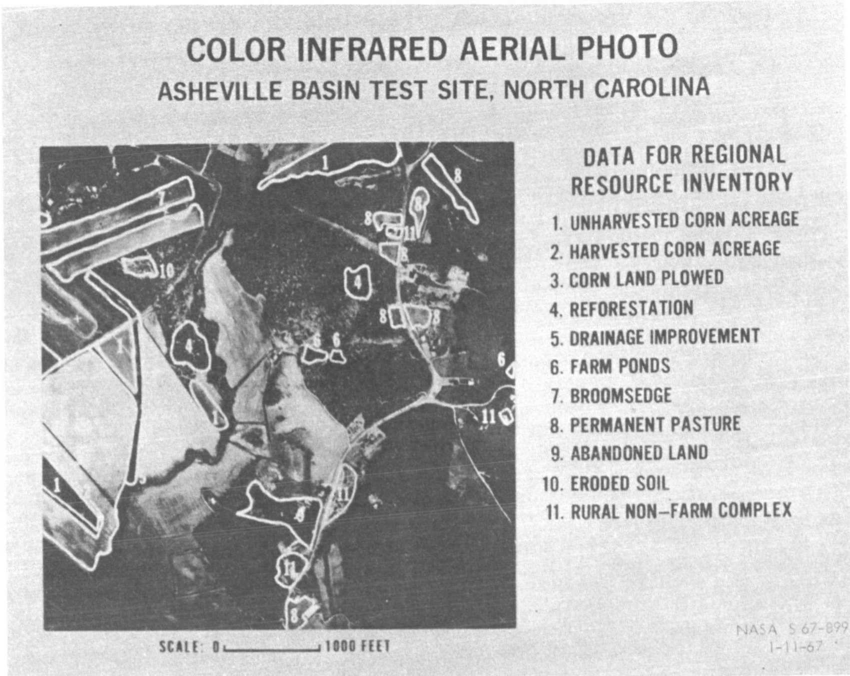

FIGURE 175

are developing jointly with them. This satellite, an improved TIROS Operational System (TOS), will carry stored pictures for global coverage and also will provide the automatic picture transmission (APT) service to more than 160 stations around the world. It now takes two satellites to perform these functions. In addition, the improved TOS will be Earth-oriented and will incorporate night cloud observations with instrumentation developed in the Nimbus program. What future operational weather satellites will be like depends heavily on further research on atmospheric sensors with the Nimbus system.

Meteorologists today are working toward a World Weather Watch wherein stations all over the world will pool their daily observations to feed superspeed computers capable of solving the equations which describe global weather circulation and predict its future behavior. Since ¾ of the world is covered by water and much of the land is not well covered with weather stations, the satellite continues to be the best hope for acquiring the global data required to forecast weather about two weeks in advance. Before this can become a reality, new instrumentation must be developed to acquire pressure, temperature, humidity, and wind velocity either by remote sensing from orbit or by collecting these data from instrumented platforms in the atmosphere. The forthcoming Nimbus B flight will test both an instrument to sense atmospheric temperature profiles and a system to collect data from automated stations and balloons. It is worth noting that satellite communications will be most helpful in collecting data from all sources and in transmitting them to the central computers.

Nimbus II, which was launched in 1966, has now been operating in a fully-stabilized mode for over 11 months, and appears to be a highly satisfactory system for continued R&D work, with relatively minor upgrading. The future trend in meteorological satellites is toward more weight and power. Accordingly, we have decided to improve the current Nimbus system. These improvements, which begin with Nimbus D, plus the procurement of Nimbus E and F, will cause an increase in Nimbus funding in Fiscal Year 1968. In amplification of this statement, a summary description of the Nimbus program can be made available to the Committee.

Another highly significant accomplishment of 1966 was the successful first flight of the Applications Technology Satellite series. ATS I was placed in a synchronous orbit 22,300 miles over the Pacific (see fig. 105). From this stationary position, it can perform a large number of important experiments in meteorology, communications, space science, and technology. The ATS I can transmit a photograph of the illuminated portion of the Earth's hemisphere every 20 minutes. It can provide experimental communications between east coast stations and aircraft as far away as Japan or Australia, thus opening the way for effective transoceanic air traffic control. It provides wide band and multiple access communications for simultaneous usage. And it monitors the radiation environment in this useful and important orbit.

Later ATS spacecraft will continue to develop the technology of Earth synchronous satellites. Improved active and passive attitude control systems need to be developed. High-gain steerable antennas such as those planned for ATS F and G are required for direct broadcast of voice and television material. They will also enhance advanced systems for effective data collection, air navigation, and traffic control. These represent the most important new applications now foreseen.

Power supplies and high power transmitters must be improved. With a modest amount of R&D, these applications can become an operational reality before very many years. The broadcast satellite will be cost-effective even in this country, and will be a great boon to the developing nations that have virtually no broadcast distribution systems. The Soviet Union may be working in this direction with its Molniya communications satellites.

The Committee will be interested in reviewing separate documents describing these newest Applications Technology Satellites (F and G), which are planned to proceed into detail design with Fiscal Year 1968 funds, and the Voice Broadcast Satellite proposed for Phase B study in Fiscal Year 1968. Should the results of this latter study be as successful and promising as anticipated, we could be prepared to submit a request for detail design support in Fiscal Year 1969.

The Passive Geodetic Earth Orbiting Satellite (Pageos) completes the list of six successful applications satellites launched in 1966. This aluminized balloon in a nearly-polar orbit of 2000 miles will be useful for years of observation to tie the continental mapping networks accurately into a global system.

I will show you briefly some of the results of these programs. Figure 176 illustrates the medium resolution infrared (MRIR) imaging system carried on

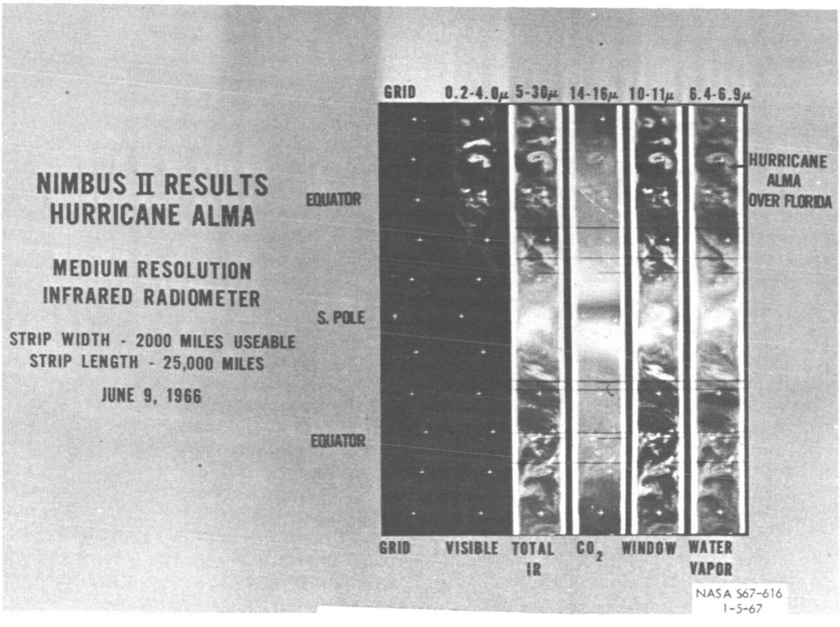

FIGURE 176

Nimbus II. This system provides day and night global coverage in five spectral bands viewing visible light, total IR, CO_2, water vapor, and the Earth through the IR "window." These data are routinely formatted as 2000-mile-wide strips that encircle the Earth from pole to pole. Note Hurricane Alma in this selected sample.

The same hurricane as observed with the three other observing systems on Nimbus II is shown in figure 177. These systems, providing both day and night coverage, will be used on the improved TOS being developed by NASA for ESSA.

The next two figures illustrate the high quality of the daylight photography being obtained with the current ESSA satellites. The APT coverage of North America as received by the combination of an east coast (Wallops Island) and a west coast (San Francisco) station is shown in figure 102. Global coverage as received daily from stored pictures is shown in figure 103 for October 31, 1966. Careful study reveals the land masses of the Earth beneath their telltale weather signatures—the clouds.

The dramatic practical results of the ATS–I are depicted in figure 105. The photograph of the Earth spans the entire Pacific Ocean and shows North America, South America, and Australia. Weather coverage of about 40% of the Earth is provided. Three synchronous satellites with proper ground control and advanced camera systems could ultimately provide continuous real-time global observation, with high resolution "zoom" viewing of any selected areas of special interest—all at the touch of a dial at a single console at the ESSA weather center. This is the shape of things to come.

Also pictured in this chart are several of the highly successful and significant communications experiments conducted with the ATS–I. In addition, a number of scientific experiments on ATS–I are now monitoring the space environment at this important altitude.

Bioscience program

The objective of this subdivision of our program is to extend the study of living organisms into the unique arena of space. One facet of the program thus involves

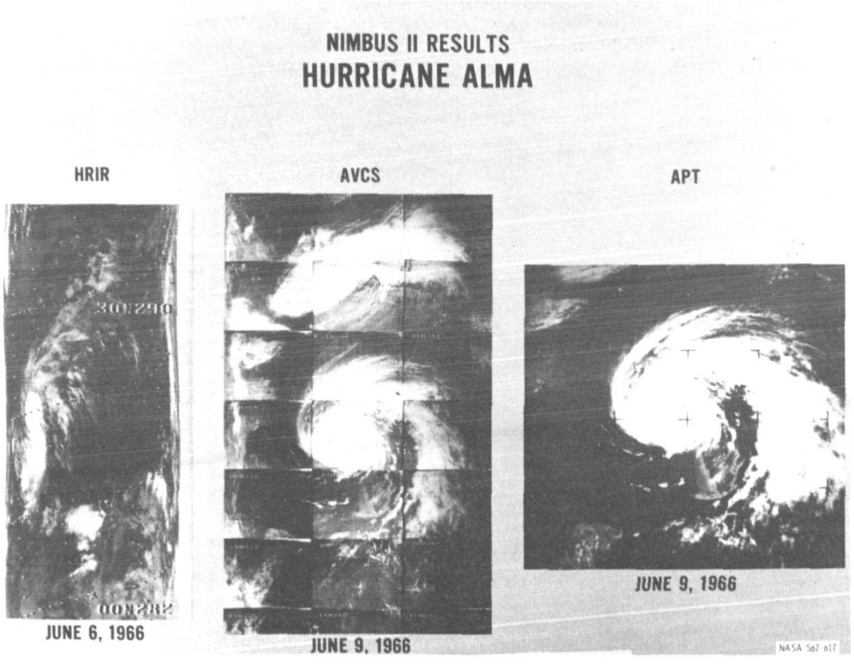

FIGURE 177

looking for effects of weightlessness and the absence of the Earth's cyclic influences on fundamental life processes from the subcellular level up to the physiology of complete mammals. A second facet of the program, the search for extraterrestrial life, is largely coupled with the Voyager program at this time.

The Bioscience program is proposed to continue at about the 1967 level as shown below, see also figure 106.

	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Supporting research and technology	$11,100,000	$11,550,000	$14,300,000
Biosatellite	23,300,000	30,000,000	30,000,000
Total	34,400,000	41,550,000	44,300,000

The slight increase in SR&T supports the accelerating Voyager effort. The Biosatellite costs are held to the 1967 level, which itself is up from that planned at the start of the year. Development cost increases have forced us to stretch this program to an extent that the final 21-day flight is now scheduled for 1969.

During 1966, the first Biosatellite was launched just 2¾ years after contractor go-ahead. For its three-day flight, it performed excellently in orbit, but during the reentry sequence the retrorocket failed to fire and we lost the satellite and all of its experiments. A back-up flight is scheduled for this July.

Manned space science

The objective of this portion of the NASA program is to capitalize on the ongoing manned space flight program to extract a maximum of return in terms of scientific results and practical applications.

In Fiscal Year 1968, the funds for this work are carried as part of the Saturn Apollo Applications program from whence they will be allocated to supporting offices.

During Fiscal Year 1967, good progress has been made on the Apollo Lunar Surface Experiment Package (ALSEP), which is a relatively sophisticated automated scientific laboratory to be emplaced on the Moon by the Apollo astronauts (fig. 178). In addition, preparations are proceeding at the Manned

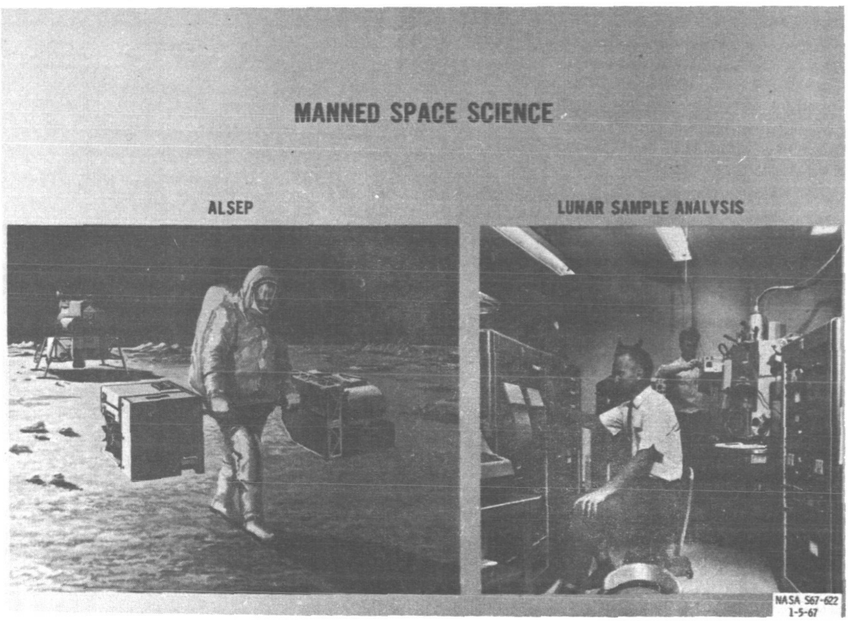

FIGURE 178

Spacecraft Center and at participating universities for analysis of the first lunar sample. Also in the lunar area, important progress has been made in the analysis of Lunar Orbiter photographs and preparation of corresponding cartography.

In support of Earth orbital manned space flight, we have indentified important payloads in the areas of solar and stellar astronomy, meteorology, Earth resources, and biology. The farthest advanced of these payloads is the Apollo Telescope Mount (ATM), which was described to this Committee in the Fiscal Year 1967 hearings. Development of the flight hardware is being successfully conducted under the direction of the Office of Manned Space Flight and the Marshall Space Flight Center.

Some results of scientific experiments conducted in Gemini flights are shown in figure 179. The spectacular color photograph of India is but one of hundreds being used to explore the utility of such photography in geology and Earth resource surveys. The spectrum of the star, Canopus, shown on the right, illustrates the ability of astronomical observations to detect portions of the spectrum, and hence stellar elements, not visible through the Earth's atmosphere. This spectrum is the first to show absorption lines in the 2200–3000 Angstrom wavelength region of a star other than the Sun. The presence of magnesium, silicon, and ionized iron were identified. Future instruments will greatly increase the resolving power.

Sustaining University Program

The primary objective of this important program is to advance the growth and capability of American colleges and universities in the fields of space science and engineering. In addition, the involvement of educational institutions in the broad multidisciplinary space effort has served as a catalyst to interdepartmental cooperative efforts on broader problems than those related to the space program alone.

The program has helped to maintain the continuing supply of highly trained scientists and engineers so vital to our government laboratories, the aerospace industry, and to the faculties of colleges and universities. It has strengthened the university role in the scientific exploration of space, which contributes so much to the NASA program.

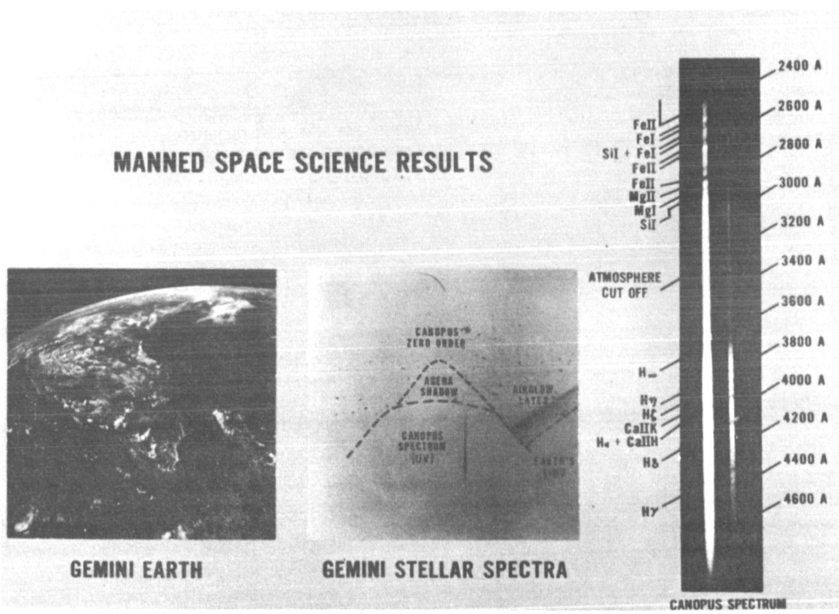

FIGURE 179

This support involves training grants for graduate students, research grants for multidisciplinary space-related research, and facilities grants where desirable growth is retarded by lack of facilities. See table below and figure 107 which shows the distribution of this support.

	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Training	$25,290,000	$16,000,000	$7,000,000
Research	12,860,000	11,000,000	10,000,000
Research facilities	7,850,000	4,000,000	3,000,000
Total	46,000,000	31,000,000	20,000,000

Despite the fact that this has been a highly successful program, other demands for funds require us to recommend a sizeable reduction in Fiscal Year 1968. The bulk of the reduction will be taken in the area of training grants. No students will be dropped, but fewer new students will enter the program. Hopefully, other sources of graduate student support will mitigate this reduction.

The results of this program are summarized in figure 180; 3681 students are in training, and 435 Ph.D.'s were graduated by the end of 1966. One hundred and fifty-two colleges and universities are participating in the training program. Twenty-four facilities have been completed, and 11 are underway. In addition, 57 colleges and universities are participating in multidisciplinary space-related research. These results will long stand as a good investment.

Launch vehicle development

During the course of the space program, OSSA has assumed responsibility for development of three launch vehicles: Delta, Scout, and Atlas Centaur. The Delta

SUSTAINING UNIVERSITY PROGRAM

RESULTS

- TRAINING

STUDENTS IN TRAINING	3,681
PHD'S GRADUATED TO DATE	*435
PARTICIPATING UNIVERSITIES - COLLEGES	152

- FACILITIES

FACILITIES UNDERWAY	*11
FACILITIES COMPLETED TO DATE	*24

- RESEARCH

PARTICIPATING UNIVERSITIES - COLLEGES	57

*DECEMBER 31, 1966

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FIGURE 180

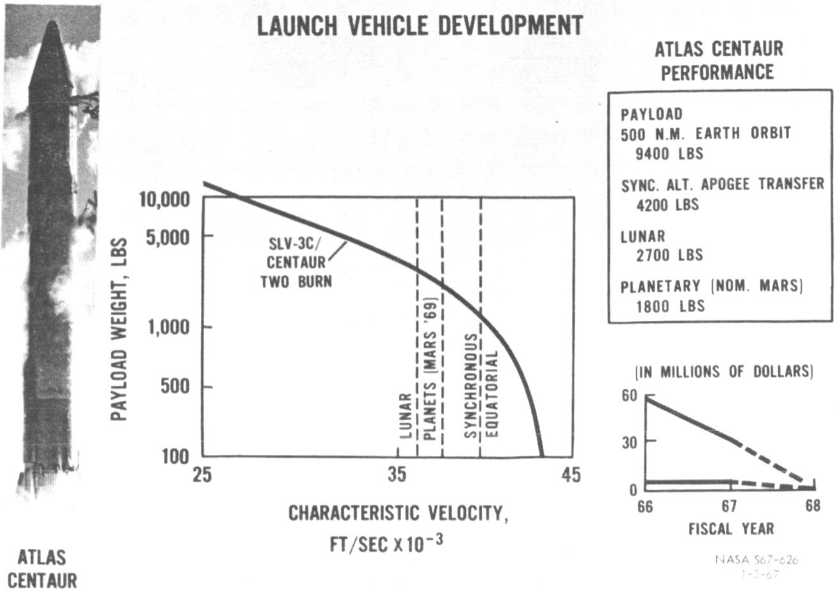

FIGURE 181

and Scout developments were completed some time ago, and both vehicles currently have long strings of consecutive successes. During 1966, the Atlas Centaur development was also completed and the performance of this vehicle is shown in figure 181. The Centaur has met or exceeded all of its original performance specifications and has successfully launched Surveyors I and II. In addition, studies have indicated it to be an attractive upper stage for Titan III, Saturn IB, and Saturn V, as well as for the 260'' solid/S–IV–B combination, if ever developed. With the Centaur stage, various combinations of these vehicles can meet all of the known requirements for automated spacecraft at least through the 1970's.

Our projected low launch rate at the Eastern Test Range (ETR) during the late 1960's has caused us to reexamine our family of launch vehicles. This problem, combined with the need for heavier payloads at high velocity, and for a high-energy upper stage of the Centaur class in the 1970's, has caused us to phase out our use of the Atlas Agena at ETR and retain the Atlas Centaur as our mainstay in this intermediate weight class. Accordingly, we plan to incorporate some simplifications into the stage during the next few years.

Launch vehicle procurement

The launch vehicle procurement picture is summarized below, see also figure 108.

	Fiscal year 1966	Fiscal year 1967	Fiscal year 1968
Supporting research and technology/advanced studies			$4, 000, 000
Scout	$11, 700, 000	$9, 400, 000	16, 800, 000
Delta	27, 729, 000	20, 900, 000	32, 600, 000
Agena	70, 669, 000	37, 100, 000	24, 700, 000
Centaur	65, 000, 000	55, 000, 000	87, 000, 000
Atlas	3, 602, 000		
Total	178, 700, 000	122, 400, 000	165, 100, 000

This year, following the completion of the Centaur development in Fiscal Year 1967, the $4.0 million continuing development efforts in Advanced Studies and Supporting Research & Technology have been consolidated with the Launch Vehicle Procurement Program. Except for Agena vehicles, procurement costs are higher in Fiscal Year 1968 than in Fiscal Year 1967, despite the projected fall-off in flights in the late 1960's. The reasons for this are relatively straightforward. Schedule delays in a number of flight projects made necessary a rephasing of vehicle procurement activity that has reduced funding requirements in both Fiscal Year 1966 and 1967. Because of prior understandings with this Committee and with the Bureau of the Budget, Fiscal Year 1966 funds were not reprogrammed to other program areas, but were carried over unobligated into Fiscal Year 1967. The extreme budgetary pressures in Fiscal Year 1967 have required making the maximum effective use of all available funds. Therefore, we have reduced Fiscal Year 1967 funding from $142.8 million to $122.4 million. This reduction was made possible by the availability of unobligated prior year funds, the schedule delays noted previously, and a very tight financial plan for funding minimum cost requirements through the end of the fiscal year.

Fiscal Year 1968 funding shown in the budget request is an amount about equal to the level of costs in Fiscal Year 1967. The dropoff due to reduced procurements will not be felt until the following year.

Construction of facilities

This budget includes an authorization request for 5 construction or alteration projects at an estimated total cost of $6,985,000 (fig. 182).

At the Kennedy Space Center Launch Complex 17, the existing Delta Service Structure and Umbilical Tower on Pad 17B will be extended 14½ feet, at an estimated cost of $2,290,000, to match the stretched-length Thor stage of the Delta launch vehicle configuration. Also included is extension of the environmental enclosure, launch deck modifications, and minor complex alterations.

A Space Flight Operations Systems Development Laboratory of 36,000 square feet, at an estimated cost of $1,195,000, is proposed for the Jet Propulsion Labo-

FISCAL YEAR 1968 CONSTRUCTION PROJECTS

SUPPORTING SPACE SCIENCE AND APPLICATIONS PROGRAM

(IN THOUSANDS OF DOLLARS)

PROJECT	LOCATION	BUDGET RECUEST
ALTERATIONS TO LAUNCH COMPLEX 17	JOHN F. KENNEDY SPACE CENTER	$2,290.0
SFOF SYSTEMS DEVELOPMENT LABORATORY	JET PROPULSION LABORATORY	1,195.0
SPACE SCIENCE RESEARCH LABORATORY	AMES RESEARCH CENTER	2,195.0
POWER AND STEAM DISTRIBUTION SYSTEM	WALLOPS STATION	740.0
UTILITY MODIFICATION AND INSTALLATION	GODDARD SPACE FLIGHT CENTER	565.0
	TOTAL	$6,985.0

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FIGURE 182

ratory. This facility will provide several small laboratories and work areas for collocating the existing Science Computer Facility, automatic data systems hardware, and the scientists and engineers of the Systems Division and Deep Space Network. Scientific and engineering design problems, software studies, and integration of the latest off-the-shelf computer hardware into operable and reliable scientific computing and mission support data capabilities will be performed in this facility.

At the Ames Research Center we are proposing a 71,500-square-foot Space Science Research Laboratory at an estimated cost of $2,195,000. This laboratory will house 120 professional personnel and over $2,000,000 of existing laboratory equipment presently located in 5 different areas on Center. The Space Science Division at Ames is heavily involved in planetology, planetary atmospheres, geology, astrophysics, and interplanetary particles and magnetic fields programs associated with automated spacecraft. Also, the areas now occupied by this Division are urgently required for expanded aeronautical research activity. This aeronautical research is now hindered because many of the Space Science research equipment and work areas are temporarily located in the hangar and shop areas.

The $740,000 Electric Power and Steam Distribution Systems renovations proposed for Wallops Station are required to replace the 20-year-old overhead power lines from Wallops Mainland to Wallops Island, portions of the Wallops Island power system, and a significant portion of the remaining overhead steam distribution lines on the main base.

At the Goddard Space Flight Center, a $565,000 Utility Modification and Installation project is proposed to convert portions of the original electric power 4160-volt distribution system to the 13,800-volt distribution system for improved reliability and standardization within the Center. Also included in this project are additional communication duct banks which will be installed in parallel with the new underground power cables to the areas of the Center where additional services are required.

These proposed construction projects are considered to be the minimum necessary additions to support the on-going research, development, launch, and space flight operations activities, and to maintain and preserve the physical plants under my cognizance.

Administrative Operations

The Administrative Operations (AO) budget (fig. 183) provides the funds for the Civil Service manpower, travel, and other normal operating expenses at the field installations for which the Office of Space Science and Applications (OSSA) has institutional management responsibility. These installations are Goddard Space Flight Center and Wallops Station. Thus, Administrative Operations supports the vital in-house effort for planning and managing the NASA programs conducted at these installations. OSSA also has institutional management responsibility for the Jet Propulsion Laboratory (JPL) which is operated under contract with the California Institute of Technology (CIT). However, the Administrative Operations costs for the Jet Propulsion Laboratory are funded from the research and development appropriation and hence do not appear in the AO budget request. The comparable dollar amount is shown on the chart for purposes of information. The NASA Pasadena Office, located at JPL, is an organizational part of OSSA Headquarters. The Administrative Operations requirements for this Office are included in the Headquarters budget request.

The NASA Pasadena Office was established in May 1966 through consolidation of the NASA Resident Office—JPL (which had responsibility for administration of the contract with the California Institute of Technology for the operation of the Jet Propulsion Laboratory) and the Contracts Division of the Western Operations Office (now called the Western Support Office).

The Administrative Operations budget provides for the compensation of 4388 Civil Service personnel, about 40% of whom are engineers and scientists. There is no change in the number of personnel at these installations between the end of Fiscal Year 1967 and Fiscal Year 1968. Personnel compensation and benefits account for over 60% of the total Administrative Operations request. The remainder is for operating expenses such as: rental and maintenance of Automatic Data Processing equipment; supplies, materials, administrative communications; maintenance and repair of buildings and grounds; and custodial and other institutional services provided under contract. The direct Adminis-

OFFICE OF SPACE SCIENCE AND APPLICATIONS
ADMINISTRATIVE OPERATIONS BUDGET - DIRECT
(IN THOUSANDS OF DOLLARS)

	FY 1967	FY 1968
GODDARD SPACE FLIGHT CENTER	$71,211	$72,240
WALLOPS STATION	10,011	10,188
TOTAL	$ 81,222	$ 82,428
*JET PROPULSION LABORATORY	$ 76,663	$ 81,355

*FUNDED FROM R & D APPROPRIATION

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FIGURE 183

trative Operations requirements for OSSA installations in Fiscal Year 1968 increased by only $1.2 million above Fiscal Year 1967. This increase is primarily to provide for additional ADP rental at Goddard Space Flight Center, resulting from the temporary overlap of equipment as third generation computers are phased in.

As previously mentioned, Administrative Operations-type expenditures at the Jet Propulsion Laboratory are funded through the contract with the California Institute of Technology and hence come under the research and development portion of the budget. However, for management purposes, we develop and administer an Administrative Operations-type budget for JPL just as we do for our Civil Service Centers. The end-of-year complement at the Jet Propulsion Laboratory is 4650 for both Fiscal Year 1967 and Fiscal Year 1968. This reflects an increase of 250 positions above the Fiscal Year 1966 level. These additional personnel were needed for Mariner '67, Mariner '69, and Voyager. The increase of $4.7 million in Administrative Operations-type expenditures at the Jet Propulsion Laboratory in Fiscal Year 1968 is due primarily to the full year cost of this additional manpower. In addition, the Fiscal Year 1968 budget provides for the lease of additional Automatic Data Processing equipment at the Space Flight Operations Facility and the Scientific Computer Facility.

Summary

In summary this is a critical year in the development of our Country's program to explore space and to apply space technology to the benefit of man. We have developed a national space capability in government, industry, and universities which is second to none. We have demonstrated this capability in a series of dramatic and highly successful missions in orbit about the Earth and the Moon, on the lunar surface, and to the near planets. The program has been a tremendous intellectual and technological stimulus to the Country, and a source of pride to all.

Nearly all of our spacecraft and vehicle developments have achieved operational status. Striking advances in utility, durability, and versatility have enhanced the effectiveness of these flight systems. Many have been or soon will be phasing out, having successfully achieved their objectives.

Important and challenging goals in space science, exploration, weather, communications, navigation and traffic control, and Earth resources survey and management lie ahead. We can no longer delay selecting some of the most compelling options if we are to maintain our capability and meet the competition.

The program which I have reviewed for you has been carefully planned to meet the most urgent minimum future needs of the United States in these vital areas. Positive action now is necessary to insure a position of strength in the years ahead, and to sustain the vitality in science and technology so essential to the welfare of modern nations.

APPENDIX I

THE MEANING AND IMPORTANCE OF OUR NATIONAL SPACE PROGRAM

INTRODUCTION

The first decade of the Space Age has seen the development of a space program that has become global in character. Although initially confined to the efforts of the United States and the Soviet Union, the space effort now involves dozens of nations, each impelled by strict considerations of self interest. Each participant sees in the space program definite expectations of return on the investment it is making, a return that ranges from valuable practical applications to pure science, and has an impact on education, economy, national and international politics, international law, and philosophy.

The space program of the United States is a broad wide-ranging, substantial fraction of the world's space effort. Being carried out by the National Aeronautics and Space Administration and the Department of Defense, it enlists the efforts of industry, government establishments, universities, and private research organizations. The United States program is linked in one way or another with virtually every other space program in the world. In the decade since it began, the program has turned out thousands of research papers and reports on new technology, new knowledge of our planet, the solar system, and the universe, and has made numerous practical applications in the fields of meteorology, communications, navigation, geodesy, and national defense. The program has clearly established the possibility of manned space flight, and has laid the initial groundwork for human operations in the new dimension of space.

THE OBJECTIVES OF THE SPACE PROGRAM

There are many motivations underlying the support of our national space program. The more immediate objectives were set forth in the Space Act of 1958, and our appreciation of their import has continued to grow as we carry out the many tasks undertaken in the program. Among the stated objectives are the advancement of human knowledge of the Earth and space, the advancement of space and related technology, the development of manned space flight, and the use of space knowledge and technology for specific practical applications.

But beyond the immediate objectives there quickly emerged a broader, more important overall objective the full significance of which becomes clearer as we continue to move ahead. This broader objective is the establishment and maintenance of a strong, national capability to operate in space and to use space fully in the national interest. Thus, while our scientific and applications satellites, deep space probes, and manned flights have been effectively meeting many of the more immediate objectives, they have also been strengthening the sinews and extending the power of our overall national space capability. Right now, we are able to operate by automated techniques from near the Earth out to hundreds of millions of miles into interplanetary space, and we are on the threshold of extensive operations with man in space.

Our national space capability is multi-faceted. On the one hand there are the many tools of the trade. These tools include, of course, the rocket and spacecraft with their hardware, namely, propulsion systems, guidance and control equipment, power supplies, radio transmitters, measuring instruments, data collection and processing equipment, and life support and recovery systems. In addition there are the industrial complexes required for manufacture, assembly, test, and checkout of components, subsystems, space vehicles, and spacecraft. There are facilities for preparation and launching of space vehicles, while nets of ground stations have been established for tracking and telemetering operations.

But a space capability is a dynamic thing. It exists only so long as it is nourished and used. The most important single element of a space capability is the

national team of highly trained and experienced people in industry, in government, and in our universities and colleges, who have the know-how and the skills to build rockets and spacecraft, and who *arc cngaged* in launching them, operating them in space, and applying them to accomplishing selected national objectives.

Such a space capability, established and kept in being, provides the basis for many options. When the Space Age began, we as a nation were constrained to responding to the challenge represented by Sputnik I with whatever we could do in space. A decade later the situation is entirely different. The number of space goals that are now within reach is so great that we can set aside the question of what can we do and turn our attention to what should we do.

The most important aspect of our present posture in space is the freedom of choice we have earned in space matters. It is a freedom of choice that we must maintain. In the interests of national security, we must be in a position to exert the same type of control over our own activities in space that we exert over our use of the seas. The total dimension of space, and the scope of its potentialities, are so great that we cannot take the chance of permitting another strong nation to acquire mastery over space while we do not. We cannot allow ourselves to get into a position where some other country may deny us the use of space either for the development of our national technology and welfare, or for the defense of our nation. Certainly, we cannot, through default, permit another nation to be in the position of using space capabilities against us while we are unable to take appropriate countermeasures.

National prestige is another reason why we cannot afford to lag in the space effort. Unquestionably prestige had a great deal to do with our vigorous entry into the space program. But, as the years have gone by, some have come to question the wisdom of according any special importance to this matter of prestige. There is a tendency to equate the search for prestige with false pride and vanity.

False pride and vanity are indeed pitfalls to be avoided. Prestige is only as important as its foundation. The prestige of the wealthy is founded on the power of money. The prestige of space activity rests on the power of technology. Thus, in these times when technology plays such a pervasive role, scientific and technological prestige have a definite influence at the negotiating table, and on where other nations turn to seek guidance, and to buy technological products, services, and training. Moreover, leadership in great, imaginative, and courageous undertakings is more than vanity. It is a matter of self-respect, and even of duty. It is a matter of continuing national development. No great country can sidestep the significant challenges of the time. And space is such a challenge.

It is an intuitive understanding of these points that has led countries around the world to equate preeminence in space with technical leadership on Earth. But the impact of the space program goes beyond intuition. The impact can be seen, and felt, and documented, and may well be the most significant effect of space research and exploration.

The scope of the space program is broad, more diverse in nature than any other technical undertaking of our time, and it is unclassified. As a consequence it engages the attention of a greater diversity of scientific and technical talent than would be the case if the program were narrower or were classified. The result is a wide range of people working to make the program a success and to derive maximum benefit from it, scientific, technical. social, economic, political.

Moreover, the program deals in concepts that can be understood by everyone. It is easy to identify with the astronaut rocketing into space and in this way to share vicariously the excitement of opening this great new frontier. The effort to define and understand our environment, to explore the planets, to observe and measure the behavior of the Sun and its influence on the Earth, and to search for life on other planets, has a meaning for people that quantum electrodynamics, parity, hyperons, strangeness, quarks, and other concepts of modern physics could never have. In assuming some of the aspects of what used to be called natural philosophy, space research and exploration can engage the attention and interest of the man in the street, and can play an important role in shaping his own concept of the world and his place in the scheme of things. It has certainly caught the imagination of the younger generation, and aroused the enthusiasm. Thus, in a very real sense the space program touches virtually everyone.

But this impact is not merely emotional or intellectual. Although difficult to define item by item, the impact is also very practical in nature, because the

process of achieving success in the very demanding missions of the space effort forces advancement of technology at the very frontier of knowledge and capability in an extremely broad range of disciplines. It is worth developing this point by citing a number of examples.

The space program forces us to advance our capabilities in *energy management*. This is very clear in the case of the large space vehicles whose thrusts are measured in the millions of pounds. But it is also true at the other end of the scale where we may use very small jets for accurate pointing of a spacecraft, or even smaller quantities of energy to make a very precise measurement of the space environment. We must learn to store energy, often over long periods of time, and call it forth at the right times in the right amounts to do our bidding.

The requirement to store energy for use at selected times, leads immediately to the demand for new and better *power sources*. Not only must conventional batteries be improved, but new sources have to be developed. The demands range from fractions of a watt to megawatts, and from minutes of operation to many years. To meet these needs there is work under way on batteries, fuel cells, radioisotope-thermoelectric generators, space reactors, solar cell systems, and solar collector mirrors. It is clear that once developed these will have a broad range of applications far beyond just the space program.

It is clear that the extensive use of rockets over the past ten years and the demands of modern aeronautics force advances in *propulsion technology*. Both solid and liquid chemical propulsion have achieved an advanced status. Many propellant combinations that not long ago were regarded as exotic, such as liquid hydrogen and liquid oxygen, are now in common use. Work is underway on nuclear propulsion, and some progress is being made in plasma and electric propulsion techniques.

The field of *electronics* feels the stimulus of space demands, not only in conventional electronics, but in miniature and subminiature and microminiature components and techniques. High reliability is a must, and long lifetime an ever more frequent requirement. Better manufacturing techniques and improved testing and selection procedures must be devised. Because of the widespread use of electronics in modern work and living, the benefits of improvements in the field are immediately felt.

Materials research must provide the walls of high-temperature high-pressure combustion chambers, the linings for rocket nozzles, the nosecones for high-speed reentry bodies, plastics that can survive the space environment, photosensitive substances for detectors and energy collectors, and lubricants to function in the hostile space environment. The effect is to expand the catalog of materials available to the designers and engineers not only of space projects but of Earth-based projects as well.

The stringent requirements to conserve weight in spacecraft demands advances in the field of *structural design*. The effort to establish large optical or radio telescope facilities in space will stretch the ingenuity of the structural designer to the utmost.

We can continue the list indefinitely, discussing in similar manner communications, guidance and control, navigation and astronautics, measurement techniques, data and information management, computers, biotechnology, biomedicine, human engineering, psychology, foods, toxicants, environmental control, etc.

This is one of the greatest values of the national space program. It may be likened to a challenging exercise that a graduate student is given to solve in order to learn thereby. The more difficult and the more substantive the problem, the more he learns. The more diverse the nature of the problem, the broader the understanding the student develops. For the very same purpose, a scientific and technological exercise of the kind represented by the national space program is important in maintaining and advancing our national technical strength.

The space program is especially effective in this role because in it we attempt things that simply cannot be done without squeezing out the last few percent in performance. We operate at the very frontiers of understanding and technology. We must have success on every try or astronauts' lives may be lost in the case of manned space flight, or an opportunity may be lost in the case of missions to planets that follow timetables over which we have absolutely no control. This requires the utmost in engineering discipline from top management of a project down to the lowest working level. It demands topmost quality in planning, design, manufacture, test, and operations. To put it another way, it demands a better return on our engineering dollar than is normally required in other human endeavors.

The program, therefore, forces a growth in management capability in government and industry, a demand that is enhanced by the size, complexity, and novelty of the effort.

The benefits to the nation are substantial. As a result of this continuing scientific and technological exercise, we are in a better position as a nation to make the right decisions on important issues that involve technical considerations, such as problems of transportation, poverty, environmental control, and matters of national security. Our improving management capability is available to plan and carry out whatever solutions are decided upon. Because of their diversity and broad range, the basic elements of an expanding space capability spill over into our economy and our daily living throughout the country.

This is no longer merely a matter of academic discussion. As a result of the NASA Technology Utilization Program over the last several years, a considerable amount of documentation has been built up to establish the reality of the aforementioned benefits. About a thousand specific examples per year attest to the continuing returns from the space investment. It must be emphasized, however, that these individual cases are collectively only the top of the iceberg. The full scope and magnitude of this return are hidden in the thinking of those who for proprietary reasons don't want to reveal what they are doing, and in the often imperceptible but irresistible molding of the thinking of thousands of others who profit by the stimulus of the space program, perhaps without consciously realizing it.

In closing, it should be emphasized that the benefits to our national technical strength discussed above accrue from all of our scientific and technological activity. It is by no means asserted that the space program may claim sole credit for our scientific and technological growth. That would be patently absurd. We can derive such benefits from many large-scale scientific and technical enterprises, in oceanography, nuclear power, development of national resources, control of our environment, etc., especially if we give conscious attention to maximizing the broad-scale benefits while achieving the specialized objectives we set for ourselves. But the space program does have special importance in these respects, in that it is unclassified, broad in scope, unmatched in the tremendous spectrum of scientific and technological disciplines involved, unequaled in the challenge of environment, is of a magnitude to make its impact felt throughout the country, and demands the very best we can do simply to achieve success.

Appendix II

Comparison of US/USSR Space Science

(Robert Jastrow, Director, Institute for Space Studies, Goddard Space Flight Center, NASA)

From time to time the question is raised concerning relative standing of the United States (US) and the Union of Soviet Socialist Republics (USSR) in space accomplishments. One measure of such relative standing is obtained from a review of space-related articles in the scientific literature. Such a review has been conducted by the Goddard Institute for Space Studies.

The US and USSR journals selected as the basis for the review are listed in the detailed report. The staff of the Goddard Institute believes that these lists include every important organ of publication in space-related fields in both countries, that is, every journal which is widely read by the scientific community and in which, therefore, all results of significance are certain to be found. The lists do not include minor journals or journals which are not usually the medium of communication chosen by scientists for the publication of significant results. However, this omission applies to both US and USSR lists, and probably has little effect on the analysis of relative standing.

Because 1961 was the first year the USSR published such space-related articles in substantial numbers and because 1965 is the last year in which scientific publications are generally available in translation, this report covers only the years 1961 through 1965 inclusive. Also, the review was limited to articles in the physical sciences and does not deal with biomedical and exobiological publications.

The report contains three separate sections.

Section I breaks by year, and by journal or publication, the number of articles appearing on the subject of Satellite and Rocket Data in Astrophysics and Atmospheric Physics; Magnetospheric Physics; and History of the Solar System.

Section II similarly tabulates articles on Planetary Astronomy. This section includes numbers of articles concerning visual emissions as well as emissions at all other wavelengths. Active radar studies are also included. It does not, however, include articles reporting planetary observations carried out with the aid of rockets and satellites since these are counted in Section I.

Section III tabulates articles on Celestial Mechanics and Astronautics. The subject matter of articles included in this section ranges from theoretical discussions of 3-body problems to calculations of trajectories for entry into the atmosphere. Articles analyzing observations on the orbits of artificial satellites are included in the first section and not counted again in the third section.

Cases of multiple publication, that is, reports on the same piece of research written in slightly different ways, or with different emphases, and published in several journals, have been counted only once in the tabulation. The count of publications would be higher for both the US and USSR if multiple counts were included. The procedure followed permits one to view relative numbers as roughly equivalent to relative volume of new output.

At the end of the report is a bibliography of the individual USSR papers counted in the report.

A comparison of numbers of published articles by year and by subject shows the United States to be leading. In general, by category, by section, and by year, the numbers of USSR articles range from about 20 percent to about 80 percent of US articles published. For 1961, however, for Section I alone, which deals with Satellite and Rocket Data in Astrophysics and Atmospheric Physics, Magnetospheric Physics, and the History of the Solar System, the USSR publications amounted to 107 percent of those published by the US. But taking all three sections of the report together, the total number of publications by the USSR in 1961 is only 81 percent of the total published by the US. Of the five years covered in the report in all categories collectively, the number of USSR articles ranges from 40 to 81 percent of US articles.

The Goddard Institute has also supplied an assessment of the quality and significance of US and USSR publications in major fields of space science. This assessment is given below. It consists of the general impressions of the Director of the Goddard Institute regarding the recent literature in space science, and regarding the sources of major recent discoveries in space-related fields, supplemented by his summary of conversations with several scientists located in NASA and US universities, who are currently active in individual areas of space science, and have been keeping a close watch on the literature relating to their specialties.

The scientists consulted in this connection were Gordon J. F. MacDonald (solid Earth physics, atmospheric physics; also trapped particles, solar wind and the interplanetary medium), Richard Goody (physics of the lower atmosphere), Joseph W. Chamberlain (physics of the upper atmosphere), Wilmot Hess (trapped particles and the interplanetary medium), Patrick Thaddeus and Neville Woolf (planetary astronomy and astrophysics), Bruce Murray (planetary astronomy), Fred Haddock (radio astronomy), and A. G. W. Cameron (Moon and planets, astrophysics).

Some material also has been drawn from the detailed and excellently documented report, "Soviet Space Programs, 1962–65; Goals and Purposes, Achievements, Plans, and International Implications," prepared by the staff of the Senate Committee on Aeronautical and Space Sciences.

It is important to note that the comments offered below are subjective in that they reflect the personal judgments of the Director of the Goddard Institute, and of scientists consulted by him, regarding developments in space science which they consider to have been of exceptional importance, as compared to other developments which they view as interesting but less fundamental.

To begin, it has been noted in a previous section that the volume of USSR research in space-related fields is smaller by a factor of two or three than the volume of US research in these fields. However, most US scientists who have been in contact with their Soviet counterparts consider that the quality of USSR scientific personnel is comparable to that of US personnel. A few USSR scientists are brilliant, as good as the best American scientists; this small group provides most of the significant new ideas of fundamental importance. The

majority are capable and productive, and do the equally important research required to reap the full benefits from the developments generated by their more inspired colleagues.

Bearing in mind this parity of US and USSR scientific talent, we may expect that the number of significant new discoveries originating in the USSR in space-related fields will be roughly proportional to the volume of USSR publications in space science.* That is, a third to a half of major developments should originate in the USSR.

It is surprising to find that this is not the case: in many space-related fields, where the amount of vitally significant, interesting and carefully performed USSR research is smaller than would be indicated by the number of space science papers published in the USSR.

Magnetosphere and Interplanetary Medium. Taking up the separate fields of research in turn, we consider first the study of the magnetosphere and the interplanetary medium. In this field, the USSR had, four or five years ago, a program comparable to that of the US, both in volume of publication and in importance of new research results. In some areas, e.g., the study of charged particle populations by ion traps, excellent Soviet work preceded similar work in the US. It appears that this is no longer the case today, if we can judge by published Russian research. Almost all of the important recent work in the field has been done in the US, including the extensive mapping of the trapped particles and the magnetic field in the vicinity of the Earth, and the elucidation of the geomagnetic tail in the solar wind. If the published record is used as the basis for judgment, it seems that USSR work on trapped particles has declined substantially in recent years.

Planetary Atmospheres. A very large Soviet program has been mounted in planetary atmospheres but has been relatively unproductive. A smaller US program, involving fewer launches, has achieved significant results, including the limb-darkening data obtained on the Mariner Venus mission and the radio occultation studies of the Martian atmosphere on the Mariner Mars mission.

Lunar and Planetary Studies. Current USSR contributions in this field are more significant, relative to those of the US, than in the fields previously discussed. The USSR has scored a number of important lunar "firsts," including photography of the hidden side of the Moon, a measurement of the lunar magnetic field, a measurement of lunar surface radioactivity, and the first detailed photographs of the Moon's surface from a lunar lander. However, those USSR experiments often appear to be relatively crude, and, as a consequence, offer disappointingly little information. For example, in the USSR lunar orbiter an experiment was included for the measurement of a lunar magnetic field estimated to be in the neighborhood of 15 to 30 gammas in strength, but in the USSR paper the precision of the measurement was started to be ± 10 gammas. It can be stated with confidence that US scientists would not fly an experiment in which the uncertainty of measurement was comparable to the expected magnitude of the effect.

USSR lunar radioactivity data also appear to have been disappointingly poor. Initial statements that the level of lunar radioactivity was comparable to that of basaltic rocks have not been followed up by the publication of detailed data; it appears that the experiment was not designed to differentiate between natural radioactivity and radioactivity induced by cosmic ray bombardment, hence it yielded only an upper limit on the level of natural radioactivity.

Regarding theoretical planetary studies, an authority on the origin of the solar system and the history of the Moon and planets offers the opinion that theoretical work on these subjects in the USSR is relatively poor: he suggests, as a reason, that USSR workers in this field are not fully cognizant of the latest US results on meteorites, isotope ratios, and related geochemical studies, which are the prime source of information on lunar and planetary history. He believes that USSR laboratory and observational work in these areas is inferior to that of the US.

Physics of the Lower Atmosphere; Atmospheric Circulation; Basic Studies in Meteorology (Excluding Operational Uses of Cloud Cover Photographs). In this field the relative position of the US to the USSR is different from that noted in

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*This remark rests on the premise that the volume of open publication in the USSR reflects the volume of scientific work. This is surely not the case in all fields of Russian science and technology; however, it is probably a valid assumption for the fields of basic research which are the subject of the present report.

previously discussed fields. There is a far stronger effort in the USSR, involving greater numbers of professional scientists and students in training, than exists in the US, in all fields of basic research relating to the processes which determine climate and long-range weather patterns. Specifically, the heat balance of the Earth and its atmosphere and oceans, the geographical and temporal distribution of the solar energy input to the Earth, and other factors contributing to our understanding of the forces which control weather and climate, are the subjects of intensive research by USSR scientists in many institutes.

It is paradoxical that US satellite *observations* of these basic meteorological data are in a relatively advanced phase. The US is obtaining a rapidly increasing amount of information on solar energy input to the Earth, and on the outflow of heat from the planet to space.

However, relatively little use is being made of this basic information in the US. Arking and Rasool at the Goddard Institute are among a very small number of people who are actively interested in the application of these data to climatology, to the circulation of the oceans and atmosphere, and to the basic understanding of the processes which generate large-scale weather activities.

The USSR has a far stronger level of interest in these problems. Among senior atmospheric physicists of higher caliber in the USSR in this field, one may mention Kondratiev at Leningrad University, Budyko and Shifrin at the Physical Institute at Leningrad, and Rosenberg at the Institute of Atmospheric Physics in Moscow.

In the important field of scattering of radiation from the Earth's atmosphere, including clouds and aerosols, the USSR has a first-rate observational program and a strong theoretical activity in the interpretation of their data. In the US there is relatively little interest in this field, except, again, for a few people such as Arking at the Goddard Institute, Sekera at the University of California at Los Angeles, and, on the observational side, Nordberg at the Goddard Space Flight Center.

In general, the USSR is stronger in these areas of atmospheric science, with more students in training and more first-class theorists and observers than is the case in the US. Also, in atmospheric sciences and climatology in the USSR, there is less of a gulf between the theorist, the laboratory experimenter and the forecaster.

Astronomy and Astrophysics. This field is of special interest in a report of U.S. and USSR space science for two reasons:

First, astronomy has a special relationship to the space sciences, as noted in the report prepared by the staff of the Senate Committee on Aeronautical and Space Sciences: "Astronomy pumps the lifeblood of new ideas and new facts into the space sciences."

Second, the USSR has scientists of exceptional brilliance in theoretical astronomy—Shklovsky in particular—who have predicted many important new developments in astrophysics; and yet, the discoveries which confirmed these predictions have been made, almost without exception, by U.S. astronomers or by Anglo-American teams. Among these important new developments in astronomy are: the discovery of quasars; the discovery of explosions in galactic nuclei; the discovery of large-scale magnetic fields in galaxies; the discovery of OH molecules in the interstellar gas; the discovery of the cosmic microwave radiation or "primordial fireball radiation" (providing the only solid evidence against the steady state and for the big bang); and the discovery of localized X-ray sources in the sky.

The last item on the list—X-ray sources—leads to the discussion of space astronomy, that is, astronomy carried out above the Earth's atmosphere at wavelengths which are inaccessible to ground based telescopes. This field of space science is, according to both U.S. and USSR astronomers, the beginning of a new era in astronomy. In the U.S., Lymon Spitzer referred to the "placing (of) astronomical objects in space" as "a revolution comparable with the initial invention of the telescope." In the USSR, M. V. Keldysh, President of the USSR Academy of Sciences, said: "Of great importance for astronomy will be the launching of optical telescopes beyond the atmosphere." In 1961, at the time of the last report comparing U.S. and USSR space science research, it was clear that space astronomy stood on the threshold of major contributions to scientific knowledge. In the intervening five years, the U.S. has moved ahead vigorously in this field, and has acquired preliminary data in X-ray and gamma ray astronomy as well as much information on solar ultraviolet radiation. More recently, a

program in infrared astronomy has been initiated; it has started with ground-based observations through atmospheric windows in the infrared; is continuing with a balloon program being conducted by the Goddard Institute; and will proceed to satellite observations in the infrared as the final phase.

The USSR, on the other hand, has done little in space astronomy apart from very recent studies of solar radiation at short wavelengths.

Comments. What are the reasons for a USSR record which—with some important exceptions—has been relatively lacking in significant and accurate results? Several factors seem to be pertinent.

First, Soviet science appears to be dominated—much more heavily than in the US—by the senior members of the academic community, and, in particular, by institute directors, of whom some are conservative or parochial in their judgments on the relative importance of new research developments. Moreover, Institute direction must be responsive to the centralized control of USSR science by the Soviet Academy of Sciences. The effect of this kind of control is to suppress exceptionally original proposals for research, especially since such proposals often come from relatively young scientists. According to the same Senate Committee staff report, the great USSR physicist Kapitsa feels that Soviet science is hindered, among other factors, by the "rigorous control from outside of the institutional research." Kapitsa states that funds are not the problem. "The money for science we have, the government does not stint us, we get it more easily than the Americans . . ." The trouble, Kapitsa thinks, is that the USSR government "gives the director of the institute the money, but it severely limits him in how to make the decisions on how to spend it."

The Senate staff report concludes its analysis of Soviet astronomy with remarks to the effect that the poor showing of Soviet astronomy and associated developments in space science is partly the consequence of "production-mindedness and mission orientation."

Second, US research progresses very rapidly because a rich variety of off-the-shelf electronics equipment is available, freeing the experimenter from the need for personally constructing routine elements of his own apparatus; the availability of fast computers for data reduction and theoretical interpretation of data also is an important factor.

This productivity of US research, resulting from the ready availability of experimental equipment and computers, is the consequence of the generous level of funding for research which has characterized American science until in the postwar period.

Third, compartmentalization hinders the cross-fertilization between neighboring fields which characterizes US research. This phenomenon—the impact of developments in instrumentation and theory in one field on independent problems in another field—has been proven, in the recent history of science, to be an enormously powerful stimulus in scientific research. Perhaps it is the open character of American society which has allowed and encouraged this free multidisciplinary approach: whatever the reason, it seems possible that USSR productivity in science has suffered from what Kapitsa called "the absence of the community of feeling among scientists."

U.S. and U.S.S.R. publications in space science, 1961–65

	1961	1962	1963	1964	1965
Sec. I:					
United States	82	97	133	119	135
U.S.S.R	88	24	50	45	66
Sec. II:					
United States	54	64	86	111	120
U.S.S.R	32	51	50	56	61
Sec. III:					
United States	40	42	115	60	69
U.S.S.R	23	8	28	29	30
Cumulative:					
United States	176	203	334	290	324
U.S.S.R	143	83	128	130	157

U.S. PUBLICATIONS IN SPACE SCIENCE

Cumulative total of secs. I to III—Distribution according to journal

	1961	1962	1963	1964	1965
Journal of Geophysical Research	61	71	103	98	113
Astronomical Journal	20	29	26	28	30
Astrophysical Journal	38	42	42	59	59
Planetary and Space Science	21	4	8	11	13
Journal of Meteorology	3				
Journal of Atmospheric Sciences		11	6	5	4
Science	8	10	21	14	27
Nature	11	5	10	11	15
Icarus		7	19	17	22
Journal of the Aerospace Sciences	14	21			
AIAA Journal			94	44	41
Space Science Reviews		3	5	3	0
Total	176	203	334	290	324

Sec. I—Satellite and rocket data in astrophysics and atmospheric physics, magnetospheric physics, history of the solar system

	1961	1962	1963	1964	1965
Journal of Geophysical Research	55	65	92	34	93
Astronomical Journal	5	1	0	1	1
Astrophysical Journal	2	2	0	3	6
Planetary and Space Science	8	3	5	10	8
Journal of Meteorology	3				
Journal of the Atmospheric Sciences		9	6	4	3
Science	3	10	14	8	17
Nature	6	1	4	4	3
Icarus		3	8	1	2
AIAA Journal			2	2	2
Space Science Reviews		3	2	2	
Total	82	97	133	119	135

Sec. II—Planetary astronomy

	1961	1962	1963	1964	1965
Journal of Geophysical Research	6	4	11	12	18
Astronomical Journal	1	11	7	16	10
Astrophysical Journal	35	40	41	55	53
Planetary and Space Science	3	1	3	1	5
Journal of the Atmospheric Sciences		2	0	1	1
Science	4	0	7	5	9
Nature	5	4	6	7	10
Icarus		2	8	12	14
AIAA Journal			1	1	0
Space Science Reviews		0	2	1	0
Total	54	64	86	111	120

Sec. III—Celestial mechanics and astronautics

	1961	1962	1963	1964	1965
Journal of Geophysical Research	0	2	0	2	2
Astronomical Journal	14	17	19	11	19
Astrophysical Journal	1	0	1	1	0
Planetary and Space Science	10	0	0	0	0
Science	1	0	0	1	1
Nature	0	0	0	0	2
Icarus		2	3	4	6
Journal of the Aerospace Sciences	14	21			
AIAA Journal			91	41	39
Space Science Reviews		0	1	0	0
Total	40	42	115	60	69

U.S.S.R. Publications in Space Science

Cumulative total of secs. I to III—Distribution according to journal

	1961	1962	1963	1964	1965
Soviet Astronomy, A. J.	44	52	41	40	54
Soviet Physics, Uspekhi	2	1	4	2	1
Soviet Physics, Doklady	4	3	5	7	7
Soviet Physics, JETP	0	0	0	0	0
Academy of Sciences, U.S.S.R.:					
1. Doklady, Earth Sciences Section	7	5	2	1	2
2. Izvestia, Physical Series	0	2	0	8	0
3. Izvestia, Geophysics Series	1	3	1	0	
4. Izvestia, Atmospheric and Oceanic Physics					9
5. Izvestia, Physics of the Solid Earth					0
Artificial Earth Satellites	66	2	31		
Cosmic Research			24	50	59
Geomagnetism and Aeronomy	19	15	20	21	23
Space Science Reviews		0	0	1	2
Total	143	83	128	130	157

Sec. I—Satellite and rocket data in astrophysics and atmospheric physics, magnetospheric physics, history of the solar system

	1961	1962	1963	1964	1965
Soviet Astronomy, A. J.	6	1	1	1	3
Soviet Physics, Uspekhi	2	0	3	1	1
Soviet Physics, Doklady	3	0	0	0	1
Academy of Sciences, U.S.S.R.:					
1. Doklady, Earth Sciences Section	7	5	2	1	2
2. Izvestia, Physical Series	0	2	0	8	0
3. Izvestia, Geophysics Series	1	3	1	0	
4. Izvestia, Atmospheric and Oceanic Physics					7
Artificial Earth Satellites	56	2	12		
Cosmic Research			17	24	31
Space Science Review		0	0	0	2
Geomagnetism and Aeronomy	13	11	14	10	19
Total	88	24	50	45	66

Sec. II—Planetary astronomy

	1961	1962	1963	1964	1965
Soviet Astronomy, A. J.	26	43	36	36	46
Soviet Physics, Uspekhi	0	1	1	1	0
Soviet Physics, Doklady	0	3	5	6	6
Academy of Sciences, U.S.S.R.:					
1. Izvestia, Atmospheric and Oceanic Physics					2
Cosmic Research			2	1	3
Geomagnetism and Aeronomy	6	4	6	11	4
Space Science Reviews		0	0	1	0
Total	32	51	50	56	61

Sec. III—Celestial mechanics and astronautics

	1961	1962	1963	1964	1965
Soviet Astronomy, A. J.	12	8	4	3	5
Soviet Physics, Doklady	1	0	0	1	0
Artificial Earth Satellites	10	0	19		
Cosmic Research			5	25	25
Total	23	8	28	29	30

NOTES

1. All journals listed in the cumulative tables were examined for articles in each of the three parts of the survey.
2. All Soviet articles are dated according to the original date of publication. Page and volume numbers, however, are those of the English language translations.
3. The letters "BC" and "L" after the page number indicate "Brief Communications" and "Letters to the Editor" respectively; not all Brief Communications and Letters are marked as such.
4. The last issue of Cosmic Research (No. 6) for 1965 was not yet available in translation. Therefore, the figures given for Cosmic Research for 1965 are extrapolations based on the number of articles in the 5 available issues. All other journals were available for the entire period 1961–65.
5. The Soviet journal Radiophysics was not available in translation.
6. In the tables, dashes in any column indicates that the corresponding journal was not published in that year.
7. Throughout, the following 2 types of articles were not included:
   (*a*) Surveys and descriptive reviews (although critical reviews were included).
   (*b*) Articles describing apparatus.
8. In pt. II (Planetary Astronomy), in particular, the following categories were not included:
   (*a*) Ground-based observations of airglow, aurora, and gegenschein.
   (*b*) Radio wave studies of the ionosphere.
   (*c*) Articles dealing with solar corpuscular emission.
   (*d*) Articles dealing with solar radio bursts or flares solely in terms of their relationship to cosmic ray intensity and/or geomagnetic or ionospheric phenomena.

PART I. SATELLITES AND ROCKETS—TRAPPED PARTICLES—HISTORY OF THE SOLAR SYSTEM

1961

Soviet Astronomy—AJ (Vol. 5)

1. Ultraviolet Solar Radiation and the Transition Layer Between the Chromosphere and the Corona. G. S. Ivanov-Kholodny and G. M. Nikolskii, pp. 31–45 (rocket measuresments).
2. The Intensity of the Principal Emission Lines of the Night Sky in the Region of the Gegenschein. L. M. Gindilis and N. N. Pariiskii, pp. 72–77 (rocket measurements).
3. Earth Satellites and Geodesy. I. D. Zhonogolovich, pp. 84–90.
4. The Motion of the Space Probe Lunik III. V. T. Gontkovskya and G. A. Chebotarev, pp. 91–94.
5. Man in Space—The Dawn of a New Age in the Progress of Science. V. G. Fesenkov, pp. 155–157.
6. Lunar and Solar Perturbations of Lunik III. V. T. Gontkovskya and G. A. Chebotarev, p. 728.

Academy of Sciences, U.S.S.R.—Doklady—Earth Sciences Section (Vols. 136–141)

1. Ionization in the Earth's atmosphere and the Energy of the Sun's Short-Wave Ultraviolet Radiation. G. S. Ivanov-Kholodny, pp. 387–390.
2. Rapid Variations of the Period of Rotation About a Transverse Axis of the Second Artificial Earth Satellite. V. M. Grigorevsky, pp. 391–393.
3. Nitrogen Ions in the Earth's Upper Atmosphere and Nocturnal Ionization in Region E. V. G. Istomin, pp. 411–414.
4. The Effect of Outer Drift Currents on the Magneto-Hydrodynamic Self-Excitation of the Earth's Magnetic Field. B. A. Tverskoy, pp. 615–617.
5. Ionization in the Ionosphere at Night. G. S. Ivanov-Kholodny and L. A. Antonova, pp. 1070–1073.
6. Magnesium and Calcium Ions in the Upper Atmosphere of the Earth. V. G. Istomin, pp. 169–172.
7. Preliminary Results of an Investigation into Solar X-Rays Using Rockets and Spacecraft. B. N. Vasiliev, Yu. K. Voronko, S. L. Mandelshtam, I. P. Tindo and A. I. Shurygin, pp. 1066–1069.

Soviet Physics—Doklady (Vol. 6)

1. Radiation Measurements During the Flight of the Third Cosmic Rocket. S. N. Vernov, A. E. Chudakov, P. V. Vakulov, E. V. Gorchakov, Yu. I. Logachev, and A. G. Nikolaev, p. 43.
2. The Outer Radiation Belt of the Earth at a Height of 320 Km. S. N. Vernov, I. A. Savenko, P. I. Shavrin, V. E. Nesterov and N. E. Pisarenko, p. 874.
3. Discovery of the Inner Radiation Belt of a Height of 320 Km in the Region of the South Atlantic Magnetic Anomaly. S. N. Vernov, I. A. Savenko, P. I. Shavrin, and N. F. Pisarenko, p. 893.

Soviet Physics—Uspekhi (Vol. 4)

1. Satellites and Meteorology. K. Ya. Kondratyev, p. 441.
2. The Ultraviolet Radiation and Soft X-Rays of the Sun. I. S. Shklovskii (rocket measurements).

Academy of Sciences, U.S.S.R.—Izvestiya—Geophysics Series

1. The Distribution of Corpuscular Radiation in the Stationary Magnetic Field of the Earth. B. D. Pletnev, pp. 95–97.

Artificial Earth Satellites (Vol. 6)

1. Electron Concentration in the Ionosphere to Altitudes of 420–470 km, Measured During IGY by Means of Electromagnetic Radiation from Soviet Geophysical Rockets. K. I. Gringauz and V. A. Rudakov, p. 57.
2. Results of Measurements of the Concentration of Positive Ions in the Atmosphere, Using Ion Traps Mounted on the Third Soviet Earth Satellite. K. I. Gringauz, V. V. Bezrukikh, and V. D. Ozerov, p. 77.
3. A Study of Interplanetary Ionized Gas, Energetic Electrons, and Corpuscular Solar Emission, Using Three-Electrode Charged-Particle Traps Set Up on the Second Soviet Cosmic Rocket. K. I. Gringauz, V.V. Bezrukikh, V. D. Ozerov, and R. E. Rybchinskii, p. 122.
4. Ionized Gas and Fast Electrons in the Earth's Neighborhood and Interplanetary Space. K. I. Gringauz, V. G. Kurt, V. I. Moroz, and I. S. Shklovskii, p. 130.
5. Discovery of Approximately 10-kev Electrons in the Upper Atmosphere. V. I. Krasovskii, I. S. Shklovskii, Yu. M. Kushnir, and G. A. Bordovskii, p. 137.
6. Variation of the Positive Ion Concentration with Altitude According to Mass-Spectrometric Data Obtained with the Third Artificial Earth Satellite. V. G. Istomin, p. 156.
7. Short-Period Changes Associated with Solar Activity in the Intensity of the Nuclear Component of Cosmic Rays. L. V. Kurnosova, L. A. Razorenov, and M. I. Fradkin, p. 162.

Artificial Earth Satellites (Vols. 7 and 8)

1. Radio-Astronomical Investigations from Artificial Satellites and Cosmic Rockets. E. A. Benediktov, G. G. Getmantsev, and V. L. Ginsburg, p. 1.
2. Results of Radio-Astronomical Observations of Soviet Cosmic Rockets. V. V. Vitkevich, A. D. Kuzmin, R. L. Sorochenko, and V. A. Udaltsov, p. 20.
3. Rotation and Orientation of the Third Soviet Satellite. V. V. Beletskii and Yu. V. Zonov, p. 29.
4. The Formation of O^+_2 Ions in the Upper Atmosphere. A. D. Danilov, p. 53.
5. The Ionization of Gases Carried into the Upper Atmospheric Layers by a Satellite. S. P. Yatsenko.
6. Investigations of the Ionic Composition of the Earth's Atmosphere Performed by Means of Geophysical Rockets During 1957–1959. V. G. Istomin, p. 64.
7. The Potential of a Metal Sphere in Interplanetary Space. V. G. Kurt and V. I. Moroz, p. 78.
8. Mass Spectrometric Investigations of the Structural Parameters of the Earth's Atmosphere at Altitudes from 100 to 210 Kilometers. A. A. Pokhunkov, p. 88.
9. Ionospheric Perturbations Caused by Moving Objects. A. V. Gurevich, p. 101.
10. Investigation of the Ionosphere and the Interplanetary Gas with the Aid of Artificial Earth Satellites and Space Rockets (Methods and Some Results of Radio-Wave Experiments). Ya. L. Alpert, p. 125.

11. The Formation of Molecular Ions in the Upper Atmosphere. A. D. Danilov, p. 233.

12. The Spatial Orientation of the Outer Radiation Belt of the Earth and the Auroral Zones. E. V. Gorchakov, p. 242.

Artificial Earth Satellites (Vols. 9 and 10)

1. Peculiarities in Studying the First Photographs of the Outer Side of the Moon. Yu. N. Lipskii, p. 4.

2. Spotting Reliable Objects on the Far Side of the Moon from the First Lunik III Photographs. I. I. Breido, A. A. Markelova, and D. E. Shchegolev, p. 56.

3. Determination of the Structure and Formation of Details on the Other Side of the Moon on Photographs Obtained Under Small Phase Angles. A. V. Markov, p. 69.

4. An Attempt to Study Photometrically the Nature of the Surface Detail on the Moon's Far Side. A. V. Markov and D. E. Shchegolev, p. 79.

5. The Nature of Some Typical Details on the Map of the Moon's Far side. A. V. Khabakov, p. 82.

6. The Structure of the Surface of the Moon and the Study of the First Photographs of Its Opposite Side. N. P. Barabashov, p. 86.

7. The Location of the Inner Radiation Belt and the Magnetic Field of the Earth. E. V. Gorchakov, p. 92.

8. The Outer Radiation Belt and Aurorae. E. V. Gorchakov, p. 96.

9. Dosimetric Measurements on the Second Soviet Satellite. I. A. Savenko, N. F. Pisarenko and P. I. Shavrin, p. 101.

10. A study of the Short-Wavelength Radiation of the Sun. A. I. Efremov, A. L. Podmoshenskii, O. N. Efimov, and A. A. Lebedev, p. 139.

11. Investigation of Solar Roentgen Radiation. I. Measurements Using Geophysical Rockets. S. L. Mandelshtam, I. P. Tindo, Yu. K. Voronko, A. I. Shurygin, and B. N. Vasiliev, p. 148.

12. Investigation of the Intensity of Charged Particles During the Flights of the Second and Third Orbiting Satellite Probes. V. L. Ginzburg, L. V. Kurnosova, V. I. Logachev, L. A. Razorenov, I. A. Sirotkin, and M. I. Fradkin, p. 157.

13. Cosmic-Ray Equator According to Data Obtained on the Second Soviet Spacecraft-Satellite. I. A. Savenko, P. I. Shavrin, V. E. Nesterov, and N. F. Pisarenko, p. 182.

Artificial Earth Satellites (Vol. 11)

1. Investigations of Solar X-Ray Radiation. II. Measurements by Means of Spaceships. S. L. Mandelshtam, I. P. Tindo, Yu. K. Voronko, B. N. Vasiliev, and A. I. Shurygin, p. 1.

2. Measurement of the Solar Far-Ultraviolet Radiation of Helium. A. V. Bruns and V. K. Prokofiev, p. 17.

3. The Cosmic Ray Equator as Determined from the Data of the Third Soviet Satellite-Ship. I. A. Savenko, V. E. Nesterov, P. I. Shavrin, and N. F. Pisarenko, p. 33.

4. The Determination of Induced Radioactivity in the Second Cosmic Satellite-Ship. V. V. Matveev and A. D. Sokolov, p. 45.

5. Absolute Concentrations of Ionic Components of the Earth's Atmosphere at Altitudes from 100 to 200 km. V. G. Istomin, p. 99.

6. Ions of Extraterrestrial Origin in the Earth's Ionosphere. V. G. Istomin, p. 105.

Artificial Earth Satellites (Vol. 12)

1. Studies of the Composition of Primary Cosmic Radiation at an Altitude of 320 km. K. I. Alekseeva, L. L Gabuniya, G. B. Zhdanov, E. A. Zamchalova, M. N. Shcherbakova, and M. I. Tretyakova, p. 7.

2. Energy Spectra of Various Groups of Cosmic Ray Nuclei which were Obtained in Measurement by Means of Cerenkov Counters on Satellite-Spaceships. L. V. Kurnosova, V. I. Logachev, L. A. Razorenov, and M. I. Fradkin, p. 18.

3. A Case of a Short-Term Rise in the Intensity of Heavy Nuclei during the Flight of Satellite-Spaceship III. L. V. Kurosova, L. A. Razorenov, and M. I. Fradkin, p. 36.

4. Measurement of Radiation Doses on the Second, Fourth, and Fifth Satellite-Spaceships. I. B. Keirim-Markus, E. E. Kovalev, and L. N. Uspenskii, p. 52.

5. The Structure of the Ionized Gaseous Envelope of the Earth According to the Data of Direct Measurements of Local Charged-Particle Concentrations Carried Out in the U.S.S.R. K. I. Gringauz, p. 114.
6. Some Results of Experiments Carried Out by Means of Charged-Particle Collectors Carried by Societ Space Rockets. K. I. Gringauz, p. 131.
7. Variations in the Mean Molecular Weight of Night Air at Heights from 100 to 210 km. Shown by Mass Spectrometry. A. A. Pokhunkov, p. 145.
8. Rocket and Satellite Studies of Meteor Dust. T. N. Nazarova, p. 154.
9. On the Origin of the Condensation of Interplanetary Dust Surrounding the Earth. E. L. Ruskol, p. 159.
10. On the "Dust Envelope" of the Earth. V. I. Moroz, p. 166.

Artificial Earth Satellites (*Vol. 13*)

1. Radiation Belts of the Earth at Heights of 180–250 km. S. N. Vernov, I. A. Savenko, P. I. Shavrin, V. E. Nesterov, and N. F. Pisarenko, p. 72.
2. Soft Corpuscular Radiation at a Height of 320 km. in the Equatorial Regions. I. A. Savenko, P. I. Shavrin, and N. F. Pisarenko, p. 80.
3. Measurement of the Absorbed Dose on the Third Spacecraft-Satellite. I. A. Savenko, N. F. Pisarenko, P. I. Shavrin, and S. F. Papkov, p. 86.
4. Effect of a Decline in Solar Activity on Cosmic Ray Intensity, From 1958 and 1960 Geophysical Rocket-Probe Measurements. Yu. G. Shafer, p. 90.
5. Analysis of Results of Simultaneous Measurements of Electron Density in the Ionosphere by Means of Ionosphere Stations and Rockets. K. I. Gringauz and G. L. Gdalevich, p. 94.
6. Direct Measurement of the Night Airglow in the λ=8640 A Spectral Region. T. M. Tarasova, p. 113.
7. Gravitational Separation, Composition, and Structural Constants of the Nighttime Atmosphere at Heights from 100 to 210 km. A. A. Pokhunkov, p. 116.

Geomagnetism and Aeronomy (*Vol. 1*)

1. Investigation of the Magnetic Field of the Moon. Sh. Sh. Dolginov, Ye. G. Yevoshenko, L. N. Zhuzgov, and N. V. Pushkov, pp. 18–25.
2. Determination of the Electron Spectrum in the Outer Radiation Belt During the Flight of the Second Soviet Cosmic Rocket. Yu. I. Logachev, pp. 26–29.
3. The Possibility of Measuring the Temperature of the Upper Layers of the Atmosphere with a Narrow Tube. A. Yu. Pressman and S. P. Uatsenko, pp. 45–48.
4. The Extra-Ionospheric Current System. A. D. Shevin, pp. 160–171.
5. Mass Spectrometric Measurements of Gas Composition of the Earth's Atmosphere by Means of Rockets and Satellites. V. G. Istomin, pp. 321–328.
6. Cosmic Ray Equator According to the Data of the Third Soviet Spaceship. I. A. Savenko, V. Ye. Nesterov, P. I. Shavrin and N. F. Pisarenko, pp. 436–439.
7. Radiation Measurements in the Outer Radiation Belt on 12 February 1961 During the Flight of a Rocket in the Direction of Venus. S. N. Vernov, A. Ye. Chudakov, P. V. Vakulov, Ye. V. Gorchakov, and Yu. I. Logachev, pp. 759–61.
8. Detection of Soft Corpuscular Radiation at a Height of 320 km. in New Equatorial Latitudes. I. A. Savenko, P. I. Shavrin and N. F. Pisarenko, pp. 762–766.
9. Radiation Recording by Soviet Artificial Satellites and Space Probes. P. V. Vakulov, N. N. Goryunov, Yu. I. Logavhev and E. N. Sosnovets, pp. 767–773.
10. The Acceleration of Particles in the Earth's Outer Radiation Belt. I. P. Ivanenko and V. P. Shabanskii, pp. 774–780.
11. The Problem of the Angular and Spatial Distribution of Particles in the Radiation Belt. Ye. V. Gorchakov and M. V. Ternovskaya, pp. 781–784.
12. On the Theory of Coulomb Scattering of Fast Electrons in the Earth's Outer Radiation Belt. B. A. Tverskoy, pp. 785–791.
13. Variations in Cosmic-Ray Intensity and the Solar Wind. N. S. Kaminev, pp. 792–795.

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Soviet Astronomy—AJ (*Vol. 6*)

1. On the Nature and Origin of Comets. V. G. Fesenkov, pp. 459–464.

Academy of Sciences, U.S.S.R.—Doklady—Earth Sciences Section (*Vol. 142–147*)

1. Dust Layers in the Upper Atmosphere. A. E. Mirikov, p. 3–4 (Vol. 142) (rocket measurements).

2. Experimental Determination of the Radiation Leaving the Earth. A. V. Liventsov, M. N. Markov, Yu. I. Merson, M. R. Shamilev, pp. 6–7 (Vol. 146).
3. Measurements of the Strength of the Electrostatic Field on the Surface of a Rocket Moving in the Ionosphere. G. L. Gdalevich, p. 15–17 (Vol. 146).
4. Investigation of X Radiation from the Sun During the Total Solar Eclipse of February 15, 1961. B. N. Vasiliyev, pp. 1–2 (Vol. 142).
5. Investigation of the Lower Ionosphere by Means of Long Radio Waves and Low Frequency Radiosondes Placed Aboard Rockets. Detection of a New Ionosphere Layer. P. Ye. Krashushkin and N. L. Kolesnikov, pp. 10–11.

Academy of Sciences, U.S.S.R.—Izvestia—Physical Series (Vol. 261–6)

Transactions of the Conference on Cosmic Rays (5–15 June 1961)

1. Investigation of Radiation in Flights of Satellites, Cosmic Vehicles, and Rockets. P. V. Vakulov, S. N. Nikolaev, N. F. Pisarenko, I. A. Savenko, A. E. Chudakov, and P. A. Shavrin, p. 760–783.
2. Variations in Cosmic Rays and Electromagnetic Conditions in the Vicinity of the Earth, in Corpuscular Fluxes, and in Interplanetary Space. L. I. Dorman, p. 800–809.

Academy of Sciences, U.S.S.R.—Izvestiya—Geophysics Series

1. The Energy Sources of the Upper Atmosphere. Yu. I. Halperin, p. 174–179.
2. Interaction Between the Solar Corpuscular Stream and the Outer Geomagnetic Field in the First Stage of a Magnetic Storm. V. D. Pletne and V. V. Temny, pp. 624–625.
3. Angular Anistropy of Radiation in the Earth's Radiation Belts. A. I. Ershkovich and V. D. Pletne, pp. 896–898.

Artificial Earth Satellites (Vol. 14).

1. Measurement of the Earth's Heat Radiation into Space from a High-Altitude Geophysical Automatic Station during the Total Solar Eclipse of February 15, 1961. I. P. Averyanov, et al., pp. 48–55.
2. Spectrometric Investigation of the Ozone Layer Up to an Altitude of 60 km. A. V. Yakovleva, et al., pp. 56–68.

Geomagnetism and Aeronomy (Vol. 2)

1. Magnetic Measurements Aboard the Venus Automatic Interplanetary Station. Sh. Sh. Dolginov, Ye. G. Yevoshenko, I. N. Zhuzgov, and N. V. Pushkov, pp. 28–30.
2. The Earth's Radiation Belts at Heights of 180–250 km. S. N. Vernov, I. A. Savenko, P. I. Shavrin, V. Ye. Nesterov, and N. F. Pisarenko, pp. 31–36.
3. Some Investigations of the Nuclear Component of Cosmic Rays and the Earth's Radiation Belts Carried out on Soviet Artificial Satellites and Rockets: A Review. V. L. Ginzburg, L. V. Kurnasova, L. A. Razorenov, and M. I. Fradkin, pp. 165–195.
4. Intensity of Short-Wave Solar Radiation and the Rate of Ionization and Recombination Processes in the Ionosphere: A Review. G. S. Ivanov-Kholodny, pp. 315–316.
5. Identification of Solar Radiation Lines in the Short-Wave Region of the Spectrum $\lambda \leq$ 1100Å. G. S. Ivanov-Kholodny and G. M. Nikolskii, pp. 351–366.
6. The Geographical Distribution of Auroras and the Earth's Radiation Belts. S. I. Isayev, pp. 552–556.
7. Ionization of the Upper Atmosphere by Solar Short-Wave Radiation. G. S. Ivanov-Kholodny, pp. 561–571.
8. Preliminary Results of Measurements of the Height of Ionospheric Inhomogeneities from Artificial Earth Satellite Signals. L. M. Yerukhimov, pp. 572–574.
9. Concerning an Effect During Measurement of Electron Concentration in the Ionosphere by the Antenna Probe Method. C. G. Getmantsev and N. G. Denisov, pp. 575–577.
10. The Ring Current, Geomagnetic Disturbances and the Radiation Belts. I. A. Zhulin and I. V. Kovalevsky, pp. 848–850.
11. Some Results of Measurements of the Constant Geomagnetic Field above the U.S.S.R. from the Third Artificial Earth Satellite. Sh. Sh. Doglinov, L. N. Zhuzgov, N. V. Pushkov, L. O. Tyurimino, and I. V. Fryanzinov, pp. 877–889.

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Soviet Astronomy—AJ (Vol. 7)

1. Synchrotron Radiation of Charged Particles in a Dipole Magnetic Field. A. A. Korchok, pp. 764–771.

Academy of Sciences, U.S.S.R.—Izvestia—Geophysics Series

1. On the Role of Solar Cosmic Rays in the Formation of the Electric Component of Radiation Zones of the Earth. A. I. Ershkovich, pp. 966–967.

Soviet Physics—Uspekhi (Vol. 6)

1. Effects Produced by an Artificial Satellite Rapidly Moving in the Ionosphere or in an Interplanetary Medium. Ya. L. Alpert, A. V. Gurevich and L. P. Pitaevskii, p. 13.
2. Water Vapor in the Stratosphere. M. S. Malkevich, Yu. B. Samsonov, and L. I. Koprova, p. 390.
3. Neutral Hydrogen Near the Earth and in Interplanetary Space. V. G. Kurt, p. 701 (rocket measurements).

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1. High-Altitude Optical Station for the Investigation of the Atmosphere. A.M. Kasatkin, pp. 3–21 (Vol. 15).
2. A Transient Increase in the Intensity of the Radiation Recorded by Sputnik V on August 20, 1960. L. V. Kurnosova, L. A. Razorenov, and M. I. Fradkin, pp. 68–73 (Vol. 15).
3. Interpretation of Upper-Atmosphere Rocket Measurements Obtained with a Thermoluminescent Phosphor. T. V. Kazachevskaya and G. S. Ivanov-Kholodny, pp. 83–86 (Vol. 15).
4. On the Results of Experiments with Three-Electrode Charged Particle Counters in the Second Radiation Belt and the Outermost Charged Particle Belt. K. I. Gringauz, S. M. Balandina, G. A. Bordovskii, and N. M. Shyutte, pp. 94–100 (Vol. 15).
5. Direct Observations of Solar Plasma Streams 1,900,000 km. from the Earth on February 17, 1961 and Concurrent Observations of the Geomagnetic Field. K. I. Gringauz, et al., pp. 100–103 (Vol. 15).
6. Measurement of Electrostatic Field Strength on the Third Artificial Earth Satellite. I. M. Imyanitov and Yu. M. Shvarts, pp. 60–65, (Vol. 17).
7. Measurements of the Electrostatic Field on the Surface of Geophysical Rockets Moving Through the Upper Atmosphere. I. M. Imyanitov, G. L. Gdalevich, and Yu. M. Shvarts, pp. 66–80 (Vol. 17).
8. On the Correlation between the Period of Rotation of Satellite 1958 δ 1 and Solar Activity. V. M. Grigorevskii, pp. 81–89 (Vol. 17).
9. The Reception and Investigation of the Radio Signals Transmitted by Soviet Lunar Probes. V. A. Kotelnikov, et al., pp. 90–99 (Vol. 17).
10. Ion Exchange Processes in the Upper Atmosphere. A. D. Danilov, pp. 18–29.
11. Variations of Atmospheric Density at Heights of More than 200 km. V. V. Mikhnevich, pp. 30–42.
12. Measurements of the Electrostatic Field at the Surface of a Rocket during its Flight in the Ionosphere. G. L. Gdalevich, pp. 43–59.

Cosmic Research (Vol. 1)

1. Study of the Magnetic Field in Cosmic Space. Sh. Sh. Dolginov and N. V. Pushkov, p. 45.
2. Certain Problems in the Interpretation of Measurement Data on Outgoing Radiation Obtained with Meteorological Satellites. K. Ya. Kondratiev, p. 78.
3. Structural Characteristics of the Radiation Field of the Earth as a Planet. E. P. Borisenkov, Yu. P. Doronin, and K. Ya. Kondratiev, p. 89.
4. Upper-Atmosphere Research with the Cosmos 3 and Cosmos 5 Satellites. 2. Soft Corpuscles. V. I. Krasovskii, Yu I. Galperin, N. V. Dzhordzhio, T. M. Mulyarchik, and A. D. Bolyunova, p. 104.
5. Upper-Atmosphere Research with the Cosmos 3 and Cosmos 5 Satellites. 3. High-Energy Corpuscles. V. V. Temny, p. 111.
6. Upper-Atmosphere Research with the Cosmos 3 and Cosmos 5 Satellites. 4. Density of the Upper Atmosphere at Heights of 200–230 km. M. Ya. Marov. p. 115.

7. Distribution of Helium, Nitrogen, and Argon in the Earth's Atmosphere at Altitudes of up to 430 km. A. A. Pozhunkov, p. 118.

8. Measurement of the Atmospheric Density by Means of Devices Mounted on Unoriented Satellites M. N. Izakov, p. 126.

9. A Procedure for Measuring Atmospheric Temperature with Instruments Carried by a Satellite. M. N. Izakov, p. 129.

10. Preliminary Results of a Study of Meteoric Matter Along the Trajectory of the Interplanetary Station "Mars 1." T. N. Nazarova, A. K. Bektabegov, and O. D. Komissarov, p. 137.

11. Radiation Monitoring During the Flights of the Spaceships Vostok 3 and Vostok 4. I. A. Savenko, N. F. Pisarenko, P. I. Shavrin, and V. E. Nesterov, pp. 144–145.

12. Requirements on the Accuracy of Derivation of Meteorological Data from Artificial Earth Satellites. B. M. Novikov and V. A. Zyobrikov, pp. 207–212.

13. Suprathermal O^+ Ions in the Upper Atmosphere. V. G. Istomin, pp. 217–221.

14. Mass-Spectrometric Measurements of the Distribution of He^+, N^+, O^+ NO^+ and O Ions in the Earth's Atmosphere Up to a Height of 430 km. A. A. Pokhunkov, pp. 222–224.

15. Effects of High-Energy Protons on Silicon Photocells. B. M. Golovin, G. M. Grigoreva, A. P. Landsman, and B. P. Osipenko, pp. 225–237.

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17. Density and Intensity Distributions of Charged Particles without Allowance for the Interaction in a Steady-State Geomagnetic Field. Y. D. Pletnev, p. 333.

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Appendix III. The Story of Earth's Atmosphere

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INTRODUCTION

An atmosphere is the gaseous envelope surrounding a celestial body. It stands between the body, a planet for example, and all external influences. Over the past two decades research on planetary atmospheres has involved so many lines of attack that one may have gained the impression that the work was made of bits and pieces. In one sense this is so, but the results now permit us to relate these bits and pieces into a more total or comprehensive picture of the Earth's atmosphere. The picture is by no means complete, but sufficient detail has been acquired and placed in position that the pieces are showing their overall relation, very similar in fact to the assembly of a jig-saw puzzle.

HIGHLIGHTS OF PROGRESS

The following description of some selected "highlights" of research in the Earth's atmosphere may serve to illustrate the above point.

The International Geophysical Year (IGY) provided the basis for the scientific exploration of the Earth's atmosphere with sounding rockets and satellites. One of the most important IGY results was the summary picture of our atmosphere that emerged. The upper atmosphere was found to be more complex and to undergo greater variations in temperature and density than had been expected.

In 1959, within the first year after its formation, NASA initiated a sounding rocket program to follow through on the IGY results and to investigate the many unexpected questions that had become apparent. A sounding rocket project to study upper atmospheric winds was initiated and about this same time the first upper atmospheric seasonal temperature variations from Fort Churchill, Canada, were obtained. These reports were especially intriguing because lower temperatures were found in the summertime than for the winter months in the region of the atmosphere around 50 miles in altitude.

By late 1960 sufficient density data were available from drag measurements of early satellites that a diurnal bulge was recognized. This bulge is a swelling or expansion of the Earth's upper atmosphere on the sunlit side. It follows the Sun

around the Earth and reaches a maximum at about 2:00 p.m. local time. It is a result of the heating effect of solar energy acting on the atmosphere. Also, about this same time the presence of hydrogen in significant amounts in the upper regions of the atmosphere was detected. This property is often referred to as the hydrogen geocorona. The finding was of considerable importance because it bears ultimately on the quantitative aspects of the loss of water from the Earth. This is because water that diffuses sufficiently high into the atmosphere (above approximately 75 miles) is dissociated by the energetic solar ultraviolet radiation into oxygen and hydrogen.

By 1961 sufficient data were available from many separate experiments to permit Nicolet to predict that helium must be a significant component of the atmosphere somewhat below the level in which hydrogen predominated. It was also in this year that the first preliminary results on the measurement of solar extreme ultraviolet radiation and its absorption in the upper atmosphere became available. The first twelve-foot sphere (balloon satellite, Explorer IX) for determination of atmospheric density was launched about this time. This satellite demonstrated the potential for extended density studies by this relatively inexpensive approach.

In 1962 the first measurements which questioned the commonly assumed premise of thermal equilibrium of ions and electrons in the ionosphere were obtained. These data stimulated further research in the next few years that indicated greater complexity of phenomena than could be explained by existing models and theories. The postulate by Nicolet of the previous year was verified when experimental data from the Explorer VIII satellite showed the presence of helium ions in the expected altitude region. The sounding rocket program was well underway by this time, and the first spectrometer measurements of the ultraviolet airglow and the first direct measurements of changes in the ionosphere during a solar eclipse were obtained.

In 1963 the first satellite designed specifically for studies of the aeronomy of the upper atmosphere was launched. This satellite, Explorer XVII provided the first *in situ* simultaneous measurements of atmospheric composition, density, and electron content on an extended scale. The results were the first integrated picture of the Earth's atmosphere and its variations in the altitude region studied. This same year produced the first measurement of nitric oxide in the atmosphere. This was accomplished by an ultraviolet spectrometer experiment carried by a sounding rocket. A concentration about tenfold greater than predicted by theory was found. This result has led to a re-examination of pertinent theories and models, and to a reappraisal of the laboratory measurements of reaction rates used to calculate the predicted amount.

In 1964 the first Orbiting Geophysical Observatory was launched. One of the summary findings from this mission was the first evidence linking variations in ion composition of the upper atmosphere with changes in the Earth's magnetic field. Also, by now sufficient data had been accumulated from sounding rocket measurements to indicate that strong winds and wind shears were a regular property of the 50 to greater than 150 mile altitude region of the atmosphere on a global basis.

In 1965 we launched OGO–II, the first observatory payload instrumented primarily for aeronomy and ionosphere studies. Results from this mission extended our knowledge of the relations between ion composition, magnetic field variations and solar behavior. The question of non-equilibrium of ion and electron temperatures raised in 1962 was being investigated thoroughly by this time and precise results were now becoming available to permit a quantitative assessment of this problem. This work was of great importance because the question of equilibrium, or an assumption of equilibrium in a model is a determining and critical step in the development of a realistic theory describing atmospheric processes.

In 1966 the second aeronomy satellite, Explorer XXXII was launched to continue the investigations initiated by Explorer XVII and to extend our knowledge of atmospheric behavior on a global basis. In this same year reports of preliminary measurements by mass spectrometers carried by sounding rockets into the "D" region of the ionosphere indicated the presence of heavy ions with mass greater than 48 atomic mass units. These measurements are difficult to make and require specially developed instruments. The heavy ions have aroused considerable interest and their identification awaits further research. Two principal possibilities appear to exist. The ions may be heavy complex ions of normal

atmospheric components such as nitrogen oxides, carbon oxides, and possibly water, or the ions may be elements, the components of meteoritic dust. Present evidence and theory indicate the latter to be a strong possibility.

A PRACTICAL APPLICATION

The reader may well ask himself the question, "This all sounds fine and very impressive, but what does it mean to me and to those who are not specialists in this field?" It is not easy to answer that question concisely. The pathways for the transfer of the results of basic science into new technology for mankind's benefit are usually broad and diffuse. An advance in one scientific discipline sometimes accelerates progress in fields far removed from the focal point of the original work. Often it is only years later that the real significance and impact of a new scientific finding become realized. Even in retrospect it is difficult to trace the communication train and sequence of steps involved in cross-discipline transfers of knowledge.

An example which is subject to concise description is the use of the results and latest findings to produce a description of the atmosphere in the form of a widely accepted "standard" or "model" description of the atmosphere. A "Standard Atmosphere" is a carefully evaluated summary compilation of the latest and best information available describing the conditions and character of the atmosphere for specified parameters, for instance from sea level to very high altitudes. Thus, it provides a common frame of reference for many scientific and technological undertakings. For example, in preparing designs of advanced aircraft and in evaluating performance specifications it is essential that all work be based on the same description of the atmosphere. Otherwise, no comparison of alternative designs could be meaningful. Obviously, the actual performance of an airplane which is designed on the basis of an unrealistic model atmosphere may be very different from the desired or specified performance. In addition to fulfilling the above needs, model atmospheres also serve as a necessary "yardstick" against which scientists and engineers can evaluate experimental results. For instance, measurements by many experimenters of the specific characteristics of the atmosphere under changing conditions are often compared to the properties specified in a model atmosphere. This comparison against a common reference permits an identification of areas of agreement and critical areas for further effort. A model or standard atmosphere table is essential for the design of airplanes, balloons, and the Mercury, Gemini, Apollo, and unmanned reentry spacecraft.

The need for a standard model of the atmosphere was recognized early in the history of aviation. In 1922, the first U.S. Standard Atmosphere Model was prepared by the National Advisory Committee for Aeronautics, the predecessor organization to NASA. As more and better information became available the model was periodically revised and extended to higher altitudes complimentary to the increasing capabilities of more recently developed aircraft. In 1952 the data were extended to include the results then becoming available from early sounding rocket investigations into the upper atmosphere. Later, with the coming of the satellite age, it was possible to extend the data still higher in altitude and to make the model much more comprehensive. The current U.S. Standard Atmosphere was printed in 1962. The next version to be titled "U.S. Standard Atmosphere Supplement, 1966," will be available in early 1967.

THE PRESENT ATMOSPHERE

We will now explore some fundamental questions concerning the origin, evolution, and changing nature of the Earth's atmosphere, and the close relation and mutual dependence of an atmosphere and its planet.

The largest energy source operating on the atmospheres of the planets (at least for the terrestrial ones) is solar illumination. Radiation from the Sun falls on the illuminated portion of the Earth's atmosphere at a rate of two calories per square centimeter per minute (1,400 watts per square meter). This is called the solar constant. The bulk of this energy lies in the narrow visible region of the spectrum. Much of this energy along with some infrared penetrates to the surface where it is absorbed by the ground, although a substantial fraction is rejected by being reflected from clouds. The wavelengths outside the visible region (x-ray, ultraviolet and infrared) are absorbed at various levels in the atmosphere and although the energy involved is only a small part of the solar constant it has an important influence on the upper atmosphere.

The energy that is absorbed heats the atmosphere and also produces chemical changes by breaking molecules into atoms and by ionizing components of the atmosphere. Temperature and density differences occur, and mass air motions result.

Other effects of this absorption of solar radiation by the atmosphere are not immediately obvious. The atmosphere protects life on the Earth from the injurious effects of the far ultraviolet solar radiation, and from particles occurring elsewhere in space. These particles include solar and galactic cosmic rays which are high-energy electrons, hydrogen atoms, and other atoms; and the much, much larger particles called meteorites.

The visible radiation from the Sun, except for the fraction reflected by clouds or scattered in the atmosphere, penetrates to the surface and is absorbed by the ground. Thus, the Earth's surface is heated by an appreciable fraction of the solar energy. The Earth in turn emits radiation at an intensity and in a wavelength interval determined by its temperature. For the average temperature of the surface this wavelength interval has its maximum in the far infrared region of the spectrum. Several constituents of the atmosphere, notably water, carbon dioxide, and ozone, are strong absorbers of this far infrared radiation. The absorption of this energy heats the lower atmosphere which in turn reradiates energy—part upward into space and part downward to provide additional heating to the surface. This return of infrared energy from the atmosphere is referred to as the "greenhouse" effect. The combination of direct solar heating and the greenhouse effect heat the Earth's surface to an average temperature of about 60 degrees Fahrenheit.

Clouds are composed of water vapor and therefore are strong absorbers of the surface emitted infrared energy. Consequently, they produce a strong and variable greenhouse effect. All of us are familiar with the greater rate with which temperature drops on a clear cloudless night as compared to a night when the sky is covered with thick clouds. This is an effect of clouds which is in addition to their effect as reflectors of part of the incident solar energy. Thus, the Earth's cloud cover is a very important factor in determining energy inflow and outflow and thereby surface temperature.

Although the atmosphere on Earth seems thin to us, the weight of the atmosphere averages out to about two million tons per inhabitant. On the other hand, if the atmosphere were condensed into a uniform layer having the density of water, the layer would be only about 30 feet deep all over the entire globe.

Atmospheres are described and studied in terms of composition, temperature, and pressure, and the variations of these quantities with altitude. This is insufficient, however, because the complex mass motions resulting from heating, and the chemical changes that result in the ionization of certain species, produce phenomena in the atmosphere that are more complicated to describe. We now know that the atmosphere of the Earth is very dynamic, it is continually changing in properties with time of day, season, year, and solar cycle. We determine the description of the atmosphere at the time of a measurement, and it is variations from the average that are significant in understanding the short-time processes of the atmosphere. The long-time variations refer to the fundamental questions to be discussed near the conclusion of this paper.

Figure 184 summarizes a great deal of information pertaining to the Earth's atmosphere. The curve on the right hand side plots temperature against altitude. Notice that as the altitude increases from sea level, the atmosphere tends to become cooler to about 8 miles altitude, then it warms to a maximum at an interval of around 18 miles, then it cools again to another minimum around 60 miles. Above this altitude the temperature increases very, very rapidly reaching values as high as 2000 degrees Fahrenheit above 150 miles. At still higher altitudes the temperature is isothermal with altitude. The temperature is cool enough at the minimum shown around 60 miles that most of our water is kept below this altitude in the atmosphere; it is frozen out when it reaches this region and cannot diffuse rapidly into the higher atmosphere where solar ultraviolet light would decompose it into oxygen and hydrogen.

Above 110 kilometers the atmosphere becomes so thin that the light atoms and molecules tend to rise in the atmosphere and ride above the heavier molecules under the action of the Earth's gravity field. This process is called diffusive separation.

As I mentioned previously, solar ultraviolet radiation ionizes atoms and molecules. This process results in the liberation of electrons in the atmosphere

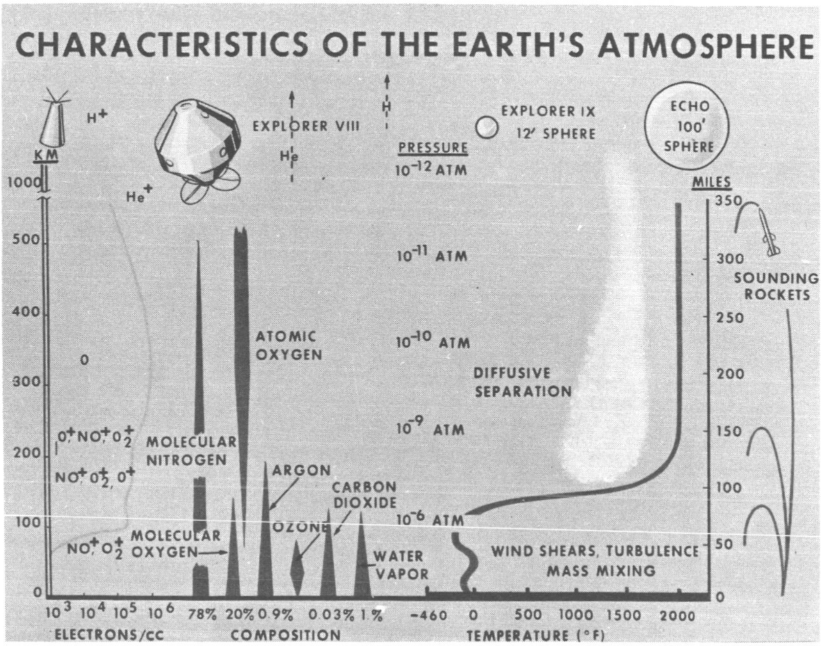

FIGURE 184

above approximately 35 miles and imparts unique and special characteristics to this region. The effect of these electrons on the propagation of radio waves is so important that the detailed study of the ionospheric aspects of the atmosphere is a discipline in its own right in the NASA program.

Some of the properties of the ionosphere are shown in figure 185. Depending upon the conditions of the ionosphere, that is the number of electrons present per cubic centimeter and upon the frequency of the radio waves, absorption, reflection, or refraction of the radio waves can take place. Obviously, if refraction takes place when we are tracking spacecraft, corrections must be made to obtain the actual position from the apparent position of the spacecraft. A very common analogy of this is the fact that when we look at a long stick which is partially immersed into water, the stick appears bent at the surface due to the refraction of light rays going from a medium of one density to another.

EVOLUTION OF OUR ATMOSPHERE

One of the basic objectives of the planetary atmospheres program is to understand the relationship of an atmosphere to its planet and to arrive at an understanding of the origin and evolution of the atmosphere. An understanding of the history of the Earth's atmosphere will contribute to a clearer picture of other planetary atmospheres which necessarily must be studied with much more fragmentary data; and, conversely, information about other atmospheres is helpful in better understanding the Earth's. While most of us appreciate the fact that the atmosphere is necessary for the existence of life, it is not so often that we realize that, if it weren't for life, we would not have an atmosphere of the type we have today.

A discussion concerning the probable evolution of the Earth's atmosphere brings forth the cross-discipline relationships that exist between the planetary atmospheres discipline and other disciplines. Our present thinking represents the following sequence. Geologic evidence indicates that our present atmosphere differs from the primitive atmosphere that may have accumulated during the

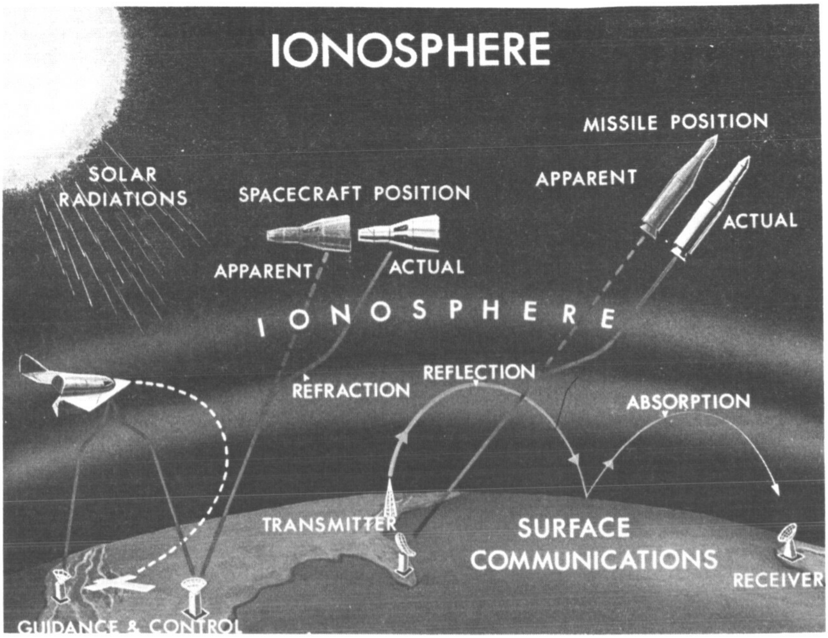

FIGURE 185

early formation and history of the Earth. Some of the evidence for this is based upon comparing the abundances of the elemental gases, such as neon (Ne) and nitrogen (N), to non-volatile elements of the Earth, and comparing these ratios with their cosmic abundances. As shown on figure 186, there is one-ten billionth the amount of neon with respect to silicon (Si) in the Earth that we would expect based upon cosmic abundances. Xenon (Xe), the heaviest of the rare gases with the exception of radon, is presently only to one millionth the amount of that we would expect based on cosmic abundances. Consequently, we believe that most of the original gases were lost early in the start of the Earth's evolution, and that the present atmosphere must have formed somewhat later. The most likely source is volcanism and this secondary atmosphere was much different than our present one. It had gases like ammonia (NH_3), methane (CH_4), sulfur oxides, hydrogen sulfide (H_2S), nitrogen oxides, and carbon dioxide (CO_2). Also water (H_2O), lots of water. But not oxygen (O_2).

The initial formation of atmospheric oxygen probably came from the photodissociation of water and to a lesser extent carbon dioxide. However, because water is frozen out of the atmosphere at high altitudes, we know that this process could not have contributed very much. The interesting and important key here is that this is a self-regulatory process in that the oxygen produced would absorb the ultraviolet energy responsible for the photodissociation. Calculations indicate that this places an upper limit of 0.1 percent of the present level of oxygen for oxygen produced in this manner. However, this was sufficient to account for the early crustal oxides. At this primitive oxygen level, lethal ultraviolet light would penetrate deeply into waters on the Earth, restricting early evolution of life to the bottoms of shallow lakes and seas. Let us examine how photosynthesis could have come about.

Beginning nearly forty years ago, the Englishman Haldane, the Russian Oparin, and the American Urey proposed and developed, in succession, a theory of the chemical origin of life according to which the basic building blocks of all living organisms—the amino acids and the nucleotides—were formed by the passage of solar ultraviolet radiation and lightning discharges through a certain

EVOLUTION OF EARTH'S ATMOSPHERE

1. ORIGINAL MOSTLY LOST; SOME H_2, NH_3, CH_4

$$\frac{Ne_E}{Si_E} = 10^{-10}\,\frac{Ne_C}{Si_C}$$

$$Xe_E = 10^{-6}\,Xe_C$$

2. SECONDARY - INTERNAL ORIGIN

   VOLCANIC H_2, N_2, CO_2, H_2O, H_2S, NH_3, CH_4

   OXYGEN LARGELY ABSENT

3. OXYGEN PRODUCTION

   $h\nu + 2H_2O \rightarrow 2H_2 + O_2$

   PHOTOSYNTHESIS

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FIGURE 186

mixture of gases which were supposed to fill the atmosphere of the Earth when it was a young planet. The gases which they had in mind were hydrogen, methane, ammonia and water vapor. These gases are made up partly or entirely of hydrogen atoms. Recently, Philip Abelson has criticized this theory of life, quite correctly pointing out that the Earth is too small a planet to keep its hydrogen. Not only would the hydrogen gas go very quickly—in about a thousand years, in fact—but the methane and ammonia molecules, which are made up of hydrogen atoms joined to carbon and nitrogen, would be broken up by solar ultraviolet rays. The hydrogen atoms released from them in this way would escape to space. Abelson proposed an alternative pathway to the chemical origin of life, based on a mixture of carbon dioxide, nitrogen and water vapor. These are the gases which come out of volcanoes at the present time.

Still more recently, Dr. Rasool of the Goddard Institute for Space Studies had an interesting thought. He speculated: Suppose that hydrogen were present in abundance in the Earth's atmosphere in the early years when the Earth was a very young planet. Dr. Holland of Princeton University argues that this was the case; his argument is that metallic iron existed in the Earth's mantle prior to the time at which the iron melted and ran to the center; this metallic iron would seize the available oxygen, and, instead of water vapor coming out of volcanoes, hydrogen would come out.

Dr. Rasool then remarks that the thermal conductivity of hydrogen gas is very high; therefore, if present in abundance, hydrogen would conduct heat away from the Earth's atmosphere very rapidly. This would lower the temperature of the upper atmosphere. At the present time the temperature of the upper atmosphere is about 1500 degrees Kelvin; at this elevated temperature hydrogen evaporates very rapidly, leaving the Earth as mentioned above, in a thousand years or less. However, Dr. Rasool has recalculated the temperature of the upper atmosphere of the Earth as it might have been in early times, when there was

an abundance of hydrogen present. He finds that the temperature would then have been 500 degrees to 700 degrees Kelvin. He further finds that the escape time of hydrogen—that is, the time during which it would remain on the Earth if 500 degrees to 700 degrees Kelvin was the range of upper atmosphere temperatures—is of the order of 100 million to 1 billion years.

In other words if hydrogen was present in abundance at the beginning, it would remain in abundance for up to a billion years. This interval is long enough for the chemical evolution of life to begin.

Theories of the evolution of life are fascinating, and I would like to quote a statement made by one of the early workers in this challenging area, Haldane, who wrote in 1928:

"When ultraviolet light acts on a mixture of water, carbon dioxide, and ammonia, a variety of organic substances are made, including sugars, and apparently some of the materials from which proteins are built up. Before the origin of life, they must have accumulated until the primitive oceans reached the constituency of a hot dilute soup."

At this time I can summarize by stating that present theories consider that increasing complexity of organized organic structures gradually evolved, and that some of these developed into systems utilizing a photosynthetic process in which carbon dioxide is consumed and oxygen is released.

Further buildup of oxygen in the atmosphere gradually took place until sufficient concentration developed to absorb most of the solar ultraviolet energy before it could penetrate to the surface. Thus, the way was prepared for life to live on the surface and be protected from the lethal ultraviolet radiation of the Sun. At this stage our atmosphere was well on its way to its present state.

SUMMARY AND FUTURE RESEARCH

Now, after having examined the possible evolution of our atmosphere as a unique property of the Earth, let us examine where we are and what lies ahead.

In the late 1940's and early 1950's before many measurements had been made with sounding rockets (the only means of getting into the upper atmosphere), it was commonly believed that the Earth's atmosphere was shallow, extending upward only a few hundred kilometers, that it was cool, and that thermal equilibrium generally existed throughout the upper atmosphere. We now know that high temperatures exist in the E region and higher, and that the atmosphere extends several Earth radii out from the planet. We also know that the upper ionosphere is not in thermal equilibrium, that is, the temperature of the electrons is different from the temperature of the ions and neutrals present. We know that strong winds and large wind shears exist in the 90 to 120 kilometer region and higher. Later studies have shown that the upper atmosphere undergoes tidal effects and oscillations called gravity waves. The most notable oscillation is the diurnal bulge, the swelling in that part of the atmosphere which is being heated by the Sun so that a bulge appears to follow the Sun in its travels about the Earth. In fact, the entire atmosphere breathes up and down in a remarkable response to variations in solar activity.

In the last year or so, we have seen a more complete development of an understanding of the transport processes in the altitude region between 50 and 150 kilometers. These processes strongly affect the upper transport of molecular oxygen into regions where it becomes dissociated by the extreme ultraviolet solar radiation.

A reasonably comprehensive picture of a planetary atmosphere, if only in an average sense, must specify the vertical distributions of composition, temperature, and density or pressure. Even in the case of the Earth's atmosphere, it is not possible at present to do this with much precision, although the general picture of the atmosphere is rather well developed. Direct measurements of atmospheric temperature and composition at certain high altitudes have proved difficult to obtain.

The problem of understanding the origin and behavior of the ionized regions of the upper atmosphere is that of understanding atmospheric chemistry—mostly photochemistry and diffusion. This cannot be done without a good knowledge of the neutral atmosphere that provides the constituents for the chemical system. The most critical region is the interval between 45 and 200 miles (about 70 and 300 kilometers).

This region is where the most important part of the absorption of solar radiation takes place and, consequently, is the most variable and important region

of the upper atmosphere. What is the effect of the variability of this region of the atmosphere on the lower atmosphere?

Figure 187 is a summary of important work to be done in the altitude region from approximately 70 to 300 kilometers. Studies must include geographical—that is, latitudinal effects—as well as diurnal and seasonal variations. The types of experiments to be done are not new. What is new, is the increased emphasis on this region of the atmosphere.

Figure 188 illustrates the problem. Satellites can go only so low, and balloons can go only so high. Sounding rockets can traverse the forbidden region; but the time for measurements is very short, and the opportunities for geographical coverage are very limited.

At this time, preliminary studies indicate there are two methods of overcoming this limitation. A "cannon ball" satellite, one with a very high mass-to-area ratio would have a satisfactory lifetime at these low altitudes. More preferable would be a satellite with propulsion so it could be placed at low altitudes and given additional energy when needed to maintain altitude, or it could even be lifted to a higher altitude for additional measurements and lowered again later on. Initial studies indicate that it would be possible to make the satellite yo-yo perhaps a dozen times over several months to a year.

Thus, while I have discussed the evolution of our atmosphere and its relation to the planet, there are still many specific research tasks that could be enumerated. However, rather than review these in detail, I have tried to relate the integrated product of our knowledge to the more fundamental, and therefore remote, of the program objectives. I have prepared the way for the major research emphasis in the program in the coming years because of the new require-

SCIENTIFIC OBJECTIVES

EARTH'S ATMOSPHERE
70 TO 300 KILOMETERS

- STUDY REGION OF SOLAR ENERGY ABSORPTION

  ENERGY BALANCE

  ION AND NEUTRAL CHEMISTRY

- RELATE BEHAVIOR OF UPPER AND LOWER ATMOSPHERE

- STUDY NEUTRAL AND CHARGED PARTICLE STRUCTURE ON A GLOBAL BASIS

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FIGURE 187

ALTITUDE OF MEASUREMENT

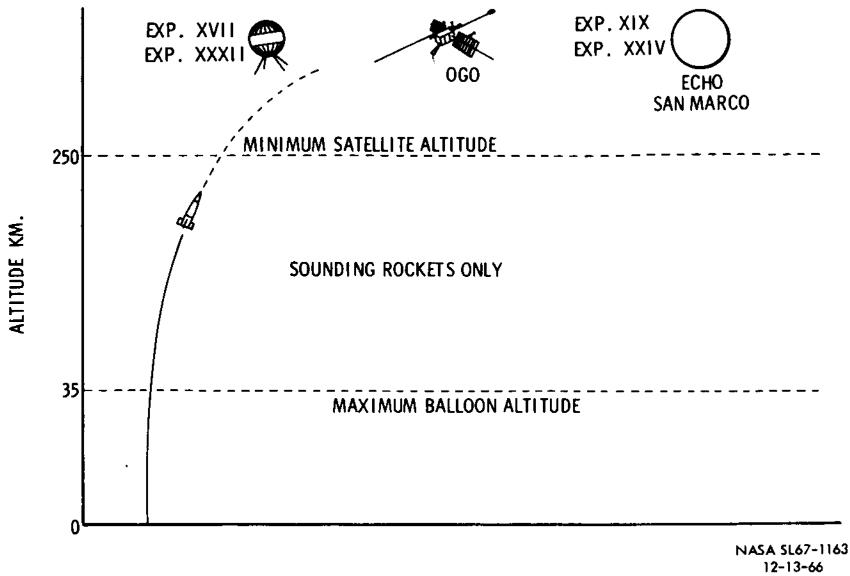

FIGURE 188

ments on our spacecraft to execute these investigations. In summary to this point, where I have used the Earth as my subject, figure 189 lists the important factors or forces determining the evolution and behavior of any planetary atmosphere.

APPLICATIONS

There are many challenging problems that could be discussed when considering the evolution of the solar system and the atmospheres of the planets. From a pragmatic view, not all of these questions are of a "blue sky" nature, nor is the information to be acquired useful to scientists only.

Let me conclude by stating some problems of current concern in the Earth's atmosphere, relating to the course and evolution of a planetary atmosphere. One might say I am discussing the future of our own "blue sky." The last decade or so has seen increasing prevalence of smog problems. The situation has worsened from being an occasional phenomenon unique to Los Angeles to a threat to most major urban areas. New York City and Pittsburgh have had serious episodes of smog with many unnecessary early deaths attributed to it. The smog problem will be solved—I can't predict how in detail—but it must be. It will require a concerted effort on the part of research laboratories, industry, local, State, and Federal governments.

It is interesting to note that smog is not caused chiefly by the initial pollutants, but by the products formed when solar ultraviolet radiation acts on contaminants such as raw gasoline, auto exhaust and industrial waste gases. The chemical changes produced by the solar ultraviolet radiation acting on the waste fumes (hydrocarbons, carbon and nitrogen oxides), create ozone, aldehydes, and other compounds far more irritating and damaging than the original contaminants.

Another problem that may be of great importance to future generations is the possible evolutionary aspects of the Earth's atmosphere from this time on. There are also other changes going on in the atmsophere that are important. The amount of carbon dioxide in the atmosphere has increased 8% in the last 60 or 70 years. These years have seen great growth in industrial activity and the advent and extensive use of the internal combustion engine. There are indic

ENVIRONMENT OF AN ATMOSPHERE

- PLANET
- PHOTON

  SOLAR RADIATION X-RAY, UV, V, IR

- ENERGETIC PARTICLES

  COSMIC RAYS
  SOLAR WIND
  VAN ALLEN RADIATION

- FIELDS

  MAGNETIC-STATIC AND VARIABLE COMPONENTS
  GRAVITY-EARTH, MOON, SUN
  ELECTRIC-LITTLE KNOWN

- LIFE

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FIGURE 189

tions that the rise in carbon dioxide concentration in the atmosphere is even more than the figure quoted, and that it is continuing to rise. The consequences of even a small increase in carbon dioxide content for the Earth's atmosphere will be a gradual increase in the average surface temperature.

This increase comes about because greater amounts of carbon dioxide will act as a blanket in the atmosphere. This would have the effect of decreasing the heat loss of the Earth into space and the average temperature of the atmosphere and the surface will rise. The polar ice caps will melt with a consequent rise in sea level. A subsequent effect would be an increased amount of water in the atmosphere. This increase would be sufficient to reflect a larger portion of the Sun's energy away from the Earth. Thus, eventually in terms of geologic time, a cooling process would set in and the surface temperature would decrease considerably below the present average value. The Earth would experience another ice age. It is considered probable that the Earth has already undergone one or more of these geologic cycles, but most likely from other causes than the one just described.

Lest the reader thinks that is the only problem future generations will have to worry about, let me mention another. There are indications that traces of pesticides and herbicides are being washed into the oceans and absorbed by marine life. Since most of the oxygen production for the Earth's atmosphere comes from the photosynthesis of marine plants, and since there is no known buffer to stabilize the equilibrium of oxygen in the photosynthesis-atmosphere cycle, the amount of oxygen in the atmosphere will decrease if the balance of the plant and animal ecology of oceans is drastically disturbed. There are about one-half million tons of oxygen per inhabitant, and any change will be quite slow and will not be perceptible for a long period of time. The concern is that

it may be impossible to make remedial changes once the situation has developed to the stage that the problem is recognizable by its effects.

Thus, in closing, I have attempted to discuss briefly our knowledge of the Earth's atmosphere and the problems we are pursuing. I have also attempted to indicate that studies of the history and evolution of a planetary atmosphere may bear on many sciences and have important practical considerations, and not be of interest solely to paleontology and archaeology.

Appendix IV. The Solar Wind and the Earth's Magnetosphere

George F. Pieper, Assistant Director for Space Sciences, Goddard Space Flight Center, NASA

INTRODUCTION

Man's interest in the Sun and in his terrestrial environment dates back to the earliest records of history. The existence of magnetism has been known since before the birth of Christ, but the fact that the Earth itself is a huge magnet was not demonstrated until 1600 A.D. when Sir William Gilbert explained how the magnetic compass may be used for navigation.

Similarly, man has observed the Sun since prehistoric times, but it has been only in the last forty years that we have begun to develop cause-and-effect relationships between events observed on the Sun (sunspots, flares, etc.) and on the Earth (auroras, magnetic storms, radio fade-outs, etc.).

Since the advent of satellite exploration of space in 1957, the term "magnetosphere" has been coined to mean the region of the Earth's influence in space—the region in which the Earth's magnetic field predominates over the solar magnetic field. Had the term existed in the early 1950's, our view of the magnetosphere during solar quiet would have been very much like (fig. 190), in

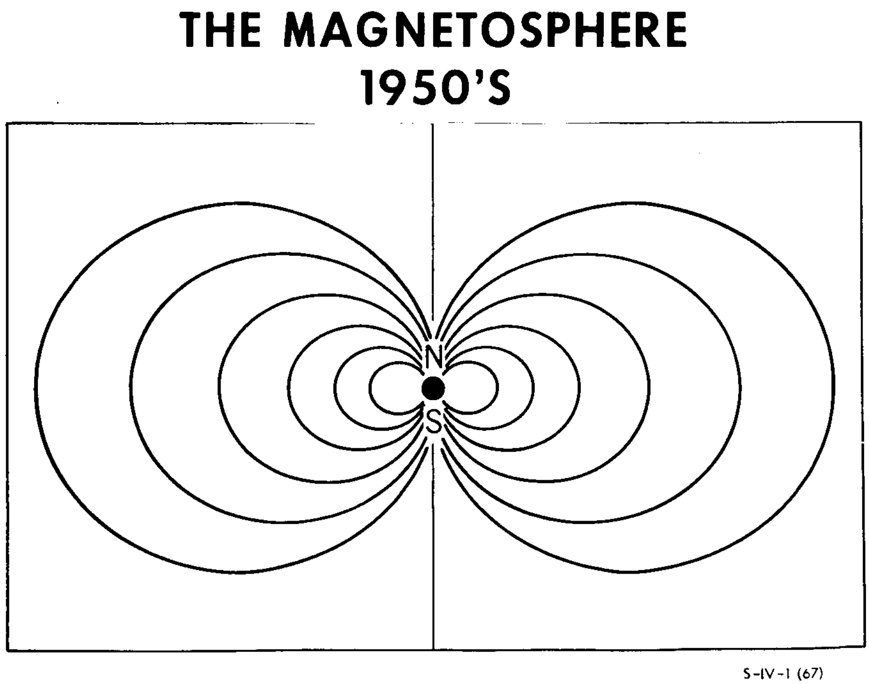

FIGURE 190

which the small circle represents the Earth and the lines represent lines of magnetic force. It is the same sort of configuration of magnetic lines of force that one obtains in the high school experiment done with a bar magnet and iron filings. As we shall see, our view of the Earth's magnetosphere is now very different from this picture of a mere decade ago.

THE BETA OF A PLASMA

In order to understand properly the relationship between the solar wind and the Earth's magnetic field, it is necessary to know just a little about the properties of a plasma. Plasma is frequently called the fourth state of matter; that is, matter may exist in the form of solid, liquid, gas, or plasma.

Plasma is defined as a collection of charged particles sufficiently dense that space charge effects can result in strongly coherent behavior. The key points about a plasma are that the matter is ionized (essentially completely, although there can be neutral particles present), that the particles can move around, and that one can describe particle behavior in bulk in much the way one can describe the behavior of a fluid in hydrodynamics. This leads in fact to the term magnetohydrodynamics, another name for the scientific area involved.

As shown in figure 191, the beta of a plasma is defined as the ration of the particle energy to the magnetic field energy. It is evaluated by adding together the kinetic energies of all the particles in a unit of volume in the plasma and dividing that number by the energy of the magnetic field in this unit of volume. In interplanetary space, the beta of the plasma is greater than one. In the radi-

THE BETA OF A PLASMA

$$\beta = \frac{\text{PARTICLE ENERGY}}{\text{MAGNETIC FIELD ENERGY}}$$

INTERPLANETARY SPACE, $\beta > 1$

IN THE RADIATION BELTS, $\beta < 1$

IN THE NEUTRAL SHEET, $\beta = 1$

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FIGURE 191

ation belts, it is less than one. And in the neutral sheet, one particular region to be discussed later, it is equal to one.

The distinction here is that in interplanetary space the particles force the field around. With betas greater than one the particles are in control and they push the field around with them. When beta is less than one, the field is in command and controls the motion of the particles as it does in the radiation belts.

One important point to be made is that space is the only laboratory we have in which we can study the physics of certain kinds of plasmas, in particular, plasmas at low temperatures, plasmas at low density, and plasmas without collisions and wall effects.

It is in this area that some of the most fundamental physical results of the space program are going to come because this kind of experiment cannot be conducted anywhere else.

THE SOLAR WIND

Until recently the Sun was thought to be a source of plasma and of energetic particle emissions for only short periods of time following solar flares. These emissions propagated into interplanetary space and interacted with the Earth's magnetic field and with the atmosphere to produce the magnetic storms and auroras and other associated phenomena which have been known for a long time.

The work of many people, particularly Eugene Parker, in 1958, suggested that a continuous flux of plasma from the Sun should occur because of the high temperature of its surface. This plasma is the solar wind. Parker also predicted that the solar wind would pull the solar magnetic field out into what is called an Archimedes spiral, as indicated in figure 192. The plasma comes out essentially radially beyond a certain distance from the Sun and the magnetic field lines come out in the Archimedes spiral.

EFFECT OF SOLAR WIND ON SOLAR MAGNETIC FIELD

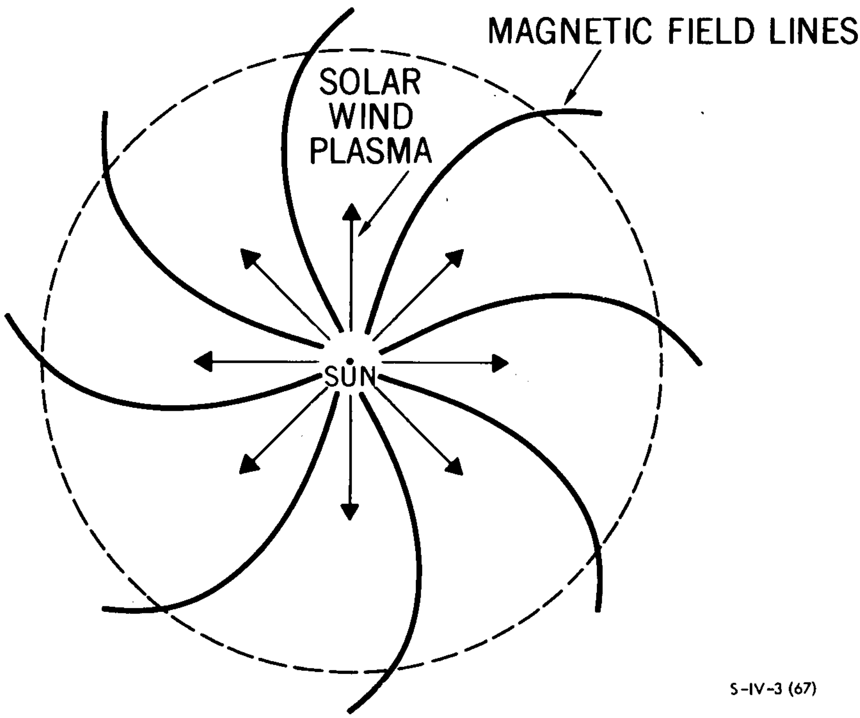

FIGURE 192

An Archimedes spiral is just another name for the sort of thing you would see if you looked down from an apartment balcony on a rotary garden sprinkler, so one sometimes hears the term garden hose effect.

The results of experiments that have been conducted on Mariners, Pioneers, OGO's, IMP's and other Explorers have revealed the characteristics of the interplanetary magnetic field and have established the nature of the solar wind to be essentially as proposed by Parker. Nearly all we know about this subject we have learned since 1958.

The nominal values and ranges of values for some characteristics of the solar wind are shown in fig. 193. We know about its velocity, its density at the orbit of Earth, its flux, energy, composition, and magnetic field. These data were obtained through our experimental research. You see that we have learned a great deal.

We have also learned, as shown schematically in figure 194, that the solar wind does indeed pull the field out in the Archimedes spiral or garden hose direction. We have learned too, that there is a sector structure to the magnetic field. If you could sit at the orbit of Earth in a spacecraft and watch the field go by as the Sun rotates in its 27-day cycle, you would find that for some periods of time the direction of the field is predominantly away from the Sun with an angle which is at about 45 degrees to the radial vector. That is the garden hose angle. You wait a while longer and the direction will change and be predominantly inward. Then later predominantly outward and still later predominantly inward. Again, I emphasize the word "predominantly" here, because there are averages of the field direction taken over several hours. When shorter periods are used, very large fluctuations from those predominant directions are seen.

If you look at figure 194 carefully, you may say there are more solar magnetic field lines coming out than there are going in. How can that be unless there are free magnetic poles? The answer is that we have only examined the situation in the plane of the ecliptic. We don't know what the field is outside that one particular plane of space. The kind of result we have obtained is shown in detail in figure 195. This is a sophisticated chart but it is based on the actual data and proves the point. If you were to measure the direction of the field and if it were isotropic, that is, if it had the same magnitude in all directions averaged

SOME NOMINAL CHARACTERISTICS OF THE SOLAR WIND

	NOMINAL	RANGE
VELOCITY	500	300-700 km/sec
DENSITY AT 1 AU	10	3-70 protons/cm^3
FLUX AT 1 AU	5×10^8	10^7-10^9 protons/cm^2-sec
ENERGY	1	0.4-4 kev/proton
COMPOSITION	H, few % He	<10% He
MAGNETIC FIELD	6	3-15 gamma

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FIGURE 193

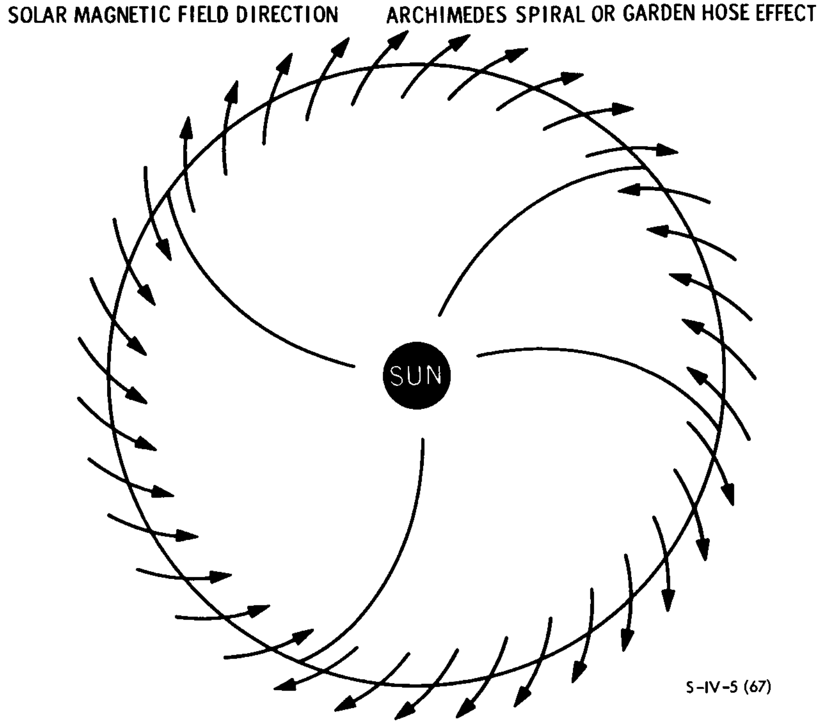

FIGURE 194

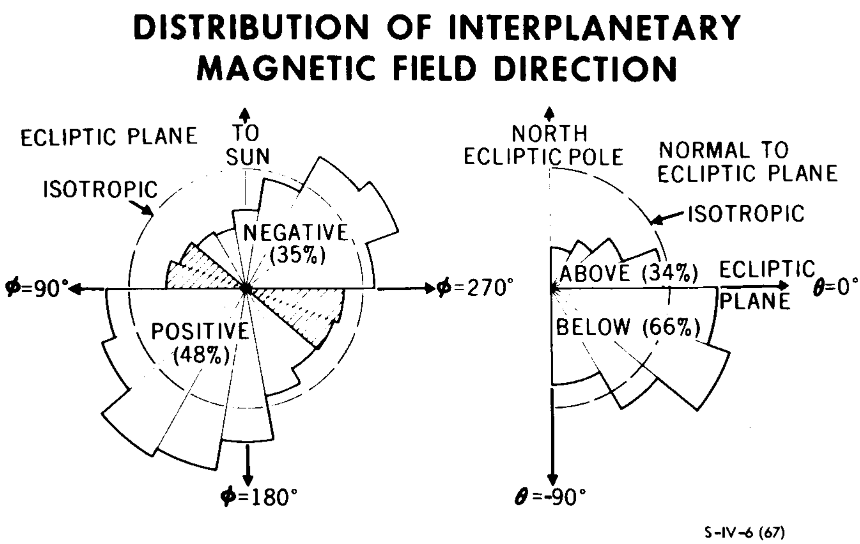

FIGURE 195

over time, then you would see, looking in the ecliptic plane, values that would go to the dotted circles. There would be equal magnitudes in all directions. But we don't see this. We see that a good part of the time the field points in a positive direction or generally away from the Sun, and other times it points in a negative direction or generally toward the Sun. In both cases, the field does not point accurately toward or away from the Sun, but rather at an angle of about 45 degrees west of the Sun. This observation determines the fact that the solar magnetic field has the Archimedean spiral structure predicted by Parker.

Similarly, we find that the field does not lie in the plane of the ecliptic but rather below it a good part of the time. We obviously have to get out of the plane of the ecliptic to determine the complete configuration of the solar magnetic field.

We have also found that the sort of pattern shown tends to remain for some period of time. It will stay until some sort of major event takes place on the Sun, a huge solar flare, for example, at which time the structure will be effectively blown apart and pushed out completely. Then a new similar structure will form and will persist for another period of time.

It sounds as if we know a lot. What then are some of the things we don't know? Shown in figure 196 are some questions with regard to the solar wind, some of the things we would like to know.

We would like to know where the solar wind originates in the Sun. The best guess is that it originates in the corona at a few solar radii from the Sun's surface. We don't know for sure.

We would like to know what the solar wind's composition is in detail. We know it is largely hydrogen, with a few percent helium, and that the percentage of helium is quite variable. We don't know why.

We would also like to know how the characteristics of the solar wind are related to other observable parameters on the Sun.

We would like to know how far out from the Sun co-rotation persists. (Co-rotation is the rotation of the solar wind plasma with the Sun.) Co-rotation is

THE SOLAR WIND

- WHAT ARE THE DETAILS OF ITS ORIGIN?
  - WHERE DOES IT ORIGINATE IN THE SUN?
  - WHAT IS ITS COMPOSITION IN DETAIL?
  - HOW ARE ITS CHARACTERISTICS RELATED TO OTHER OBSERVABLE PARAMETERS OF THE SUN?
- HOW FAR OUT FROM THE SUN DOES COROTATION OCCUR?
- WHERE DOES IT END?
  - WHAT IS THE EXTENT OF THE HELIOSPHERE?
    - IN THE ECLIPTIC?
    - OUT OF THE ECLIPTIC?
  - HOW AND WHY DOES IT VARY IN TIME?

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FIGURE 196

actually roughly demonstrated in figure 192, which is made up approximately to scale. If the dotted circle represents the orbit of Earth, then the little central dot represents the size of the Sun. The distance that is blank out to where the Archimedes spiral lines begin, is approximately 20 solar radii. That is, so far as we know, about where co-rotation stops and where the plasma begins to go radially and to drag the field with it.

How do we know it happens there? We work our way back from the orbit of the Earth where we know the beta of the solar wind plasma is considerably larger than one. We assume that the solar wind comes out spherically symmetrically although we don't know for sure. We can then make a guess as to what the magnetic field dependence on distance from the Sun is, and then work our way back to where beta would equal one. This is the point where the field would take over from the plasma, and where co-rotation would begin. It comes out to be something like 20 solar radii from the center of the Sun.

That is as much as we know about co-rotation at this time. To learn more about co-rotation will require spacecraft going in close to the Sun and spacecraft around behind the Sun.

Another point. How far out does the solar wind go? That is, what is the extent of the heliosphere where, by analogy with the term magnetosphere, I take the term to mean the region of space which is under the dominating influence of the Sun. Gravitationally the heliosphere goes out to the orbit of Pluto, 40 astronomical units. Again, from a plasma type calculation, we can take the beta of the plasma at the orbit of Earth and figure how far out we must go to make it decrease to the point where the kinetic energy of the particles per unit volume matches the energy of the magnetic field in the galaxy. From such a calculation the distance to which the heliosphere extends is something between 10 and 100 astronomical units. That is as accurately as we can tell at this time. It may be 50 or so astronomical units out there in the plane of the ecliptic.

We don't know the extent of the heliosphere out of the ecliptic plane either. And we don't know much about how and why the solar wind varies in time. Another unknown is the basic reason for the 11 year solar cycle.

So you see that while we have come a long way, we still have a long way to go before we fully understand the solar wind.

THE EARTH'S MAGNETOSPHERE

As I mentioned earlier our view of the Earth's magnetosphere today is very different from that of a decade ago. One current view that shows many of the terms involved is shown in Figure 197.

I have defined the magnetosphere as the region of the Earth's magnetic influence in space. The magnetopause is the boundary which separates the region where there are strong and oriented magnetic fields derived from the Earth, as opposed to the region outside where there are weak and fluctuating fields derived from the Sun. The solar wind impinging on the Earth's field causes field lines from the polar regions to be swept back in the anti-solar direction forming the Earth's magnetic tail. Field lines in the tail below the plane of the magnetic equator point predominantly in the anti-solar direction and those above that plane point predominantly in the solar direction. Between the two, at the equatorial plane is a neutral sheet in which the field reversal is accomplished.

The flow of the solar wind through the interplanetary medium is supersonic. Therefore, a shock wave, the bow shock, is created upstream of the obstacle (the Earth's field), in the same way that a shock wave is created upstream of an obstacle in a supersonic wind tunnel. Between the bow shock and the magnetopause is a region of turbulence, insofar as field and particle motion directions are concerned, called the transition zone.

This is all new knowledge since 1958. This view of the Earth's environment in space has been established by satellite experiments on a number of spacecraft, especially those in the IMP (Interplanetary Monitoring Platform) series, in which highly accurate magnetic field measurements were made by Dr. Norman F. Ness.

An example of the kind of data that have produced these results is shown in Figure 198 where some OGO I data are presented, showing the boundary crossings as measured by OGO. Hundreds of such crossings have occurred. The shapes of the magnetopause and the bow shock are very well delineated. They are compared here to a theory in which the Mach number, 8.7, of the incoming plasma is chosen to give a best fit to the data.

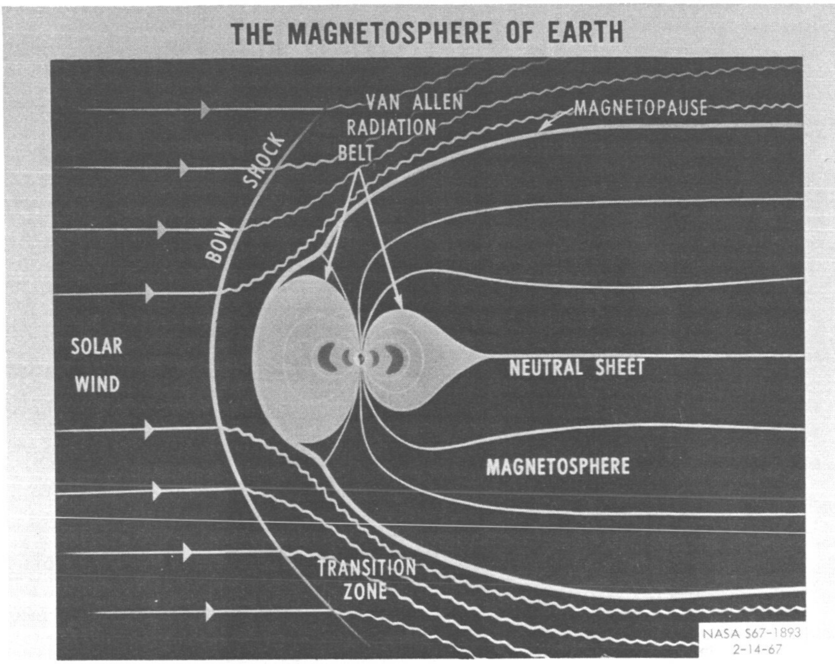

FIGURE 197

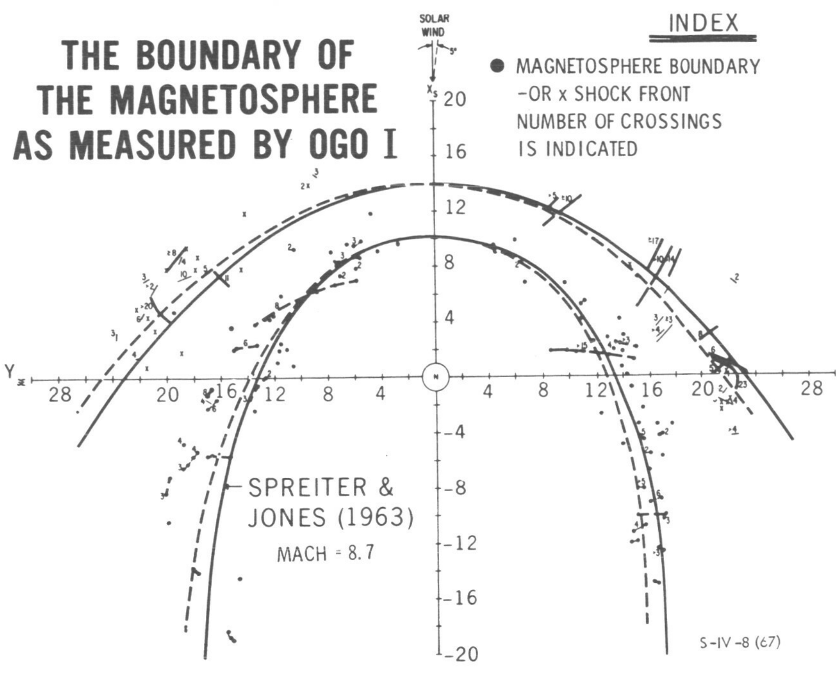

FIGURE 198

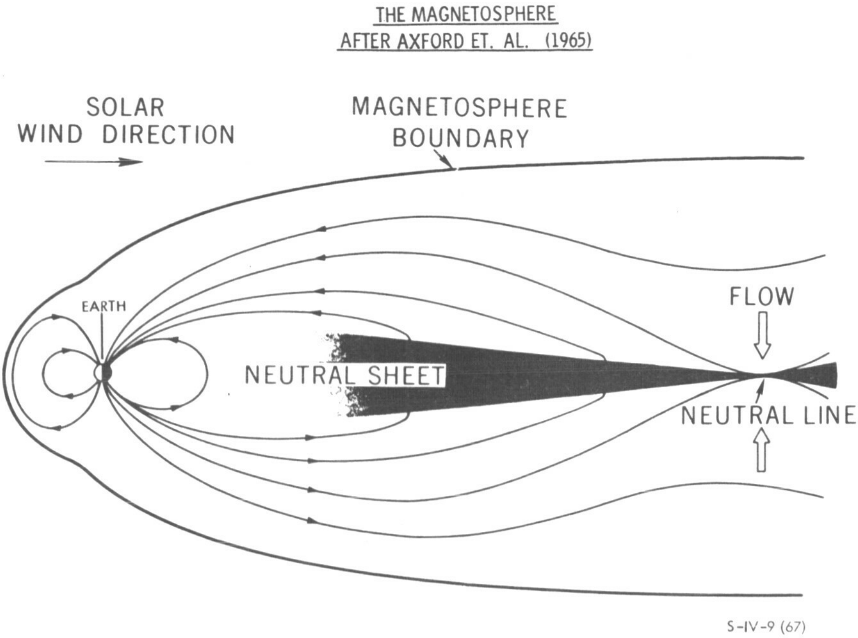

FIGURE 199

Figure 199 is a somewhat different picture.

It is a somewhat different model of the Earth's magnetic tail. The magnetic field in the region of the tail has been measured first by the first IMP, Explorer XVIII, and later by other spacecraft. We would like to know how far does the tail go? What is its detailed nature? What is the nature of the neutral sheet? You see in figure 200 and figure 199 that two different scientists have two somewhat different ideas of what the neutral sheet is. One has it as very thin and the other has quite a large volume. We don't know yet in detail which of these is correct, although it appears right now that the model shown in figure 199 has more validity than that shown in figure 200.

As a partial answer to the fascinating question of, how far does the tail go, Explorer XXXIII has recently gone well beyond the orbit of the Moon in the tail, and has made some excellent measurements out there. These show that the tail goes more than 75,000 miles beyond the orbit of the Moon.

Preliminary results, shown in figure 200, from an experiment by John Wolfe of the Ames Research Center on Pioneer VII take the story a great deal further. The figure shows the solar wind, the orbits of the Moon and of Explorer XXXIII, and the trajectory of Pioneer VII. Also shown is the "geometric shadow" of the magnetosphere, and the place where Pioneer VII detected the Earth's wake between September 25 and October 1, 1966, at a distance of some 4,000,000 miles.

I say that Pioneer VII detected wake effects, rather than the Earth's tail, because the results do not look in detail like the results of the Explorer XXXIII measurements. In fact, the cause of the wake effects is not really clear. It is presumably some form of turbulence, taking place very far downstream.

We would like also to know why and how the tail is formed? How do the particles get through the front end of the magnetosphere, if they do, to get in to form the radiation belts? Or do they enter from the back, through the tail? How does energy get transferred across the boundaries? There are numerous questions of this sort, some of which are listed in figure 201.

PIONEER VII AND EXPLORER XXXIII PROBE EARTH'S WAKE

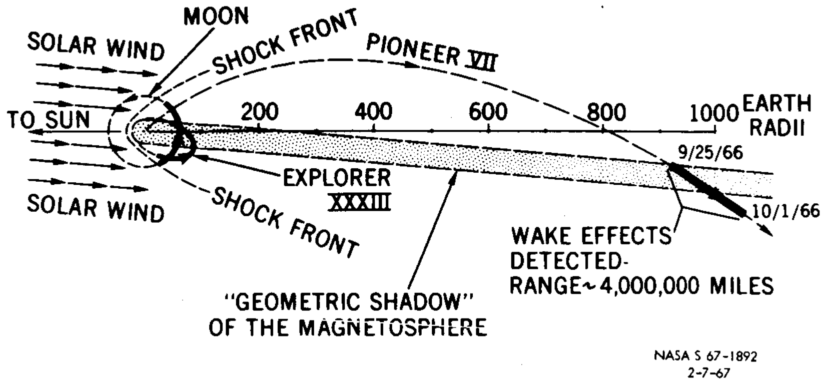

FIGURE 200

PLANETARY MAGNETOSPHERES

THE EARTH'S MAGNETOSPHERE

- WHAT IS THE NATURE OF THE BOUNDARY?
  - THE MAGNETOPAUSE?
  - THE SHOCK FRONT?
- HOW PERMEABLE IS THE BOUNDARY?
- WHY AND HOW IS THE TAIL FORMED?
  - HOW FAR DOES IT EXTEND?
- WHAT IS THE DETAILED NATURE OF THE NEUTRAL SHEET IN THE TAIL?
- HOW ARE THE RADIATION BELTS FORMED AND HOW ARE THEY MAINTAINED?
- WHAT ARE THE MECHANISMS OF ENERGY TRANSFER WITHIN THE MAGNETOSPHERE?
- HOW DO MAGNETIC STORMS AND AURORA OCCUR?

OTHER PLANETARY MAGNETOSPHERES

- ARE THERE ANY?
  - JUPITER, SATURN, MOON?

S-IV-10 (67)

FIGURE 201

When you get inside the magnetosphere to the radiation belts you find that we now know a good deal about the details of what is there. We have moved up to the second generation kind of experiments. Instead of just measuring what is there and saying this is what we have found, we can now make a measurement, figure out what ought to happen next, and see if it happens. Figure 202 shows an example of this sort of thing.

On April 17, 1965, a magnetic storm occurred which was measured by Explorer XXVI, a spacecraft that had particle detection devices and field detection instruments on board. In this chart (see fig. 202) the solid circles represent integral fluxes as a function of position in the Van Allen Belt, before the occurrence of the storm. Based on those measured pre-storm fluxes and on magnetic field measurements before and during the storm, it is possible to predict what should happen to the particle populations during the main phase of the storm when the field changes, using the theory of adiabatic invariance. The predictions are the dashed curves. The actual measurements that correspond to these predictions are the crosses. The agreement is very good in most cases.

The point to be made here is that we now have the ability in some regions of space in the radiation belt, for example, to study the dynamics of the situation, and to study what happens after perturbations. We know enough about what is going on to be able to predict what is going to happen and thus essentially to do controlled experiments.

One of the things we would like to do with a controlled experiment is to put some particles into the radiation belts and see what happens to them. It should be possible, using a particle accelerator in a satellite, to introduce very carefully a sufficient number of distinguishable particles into a shell of the radia-

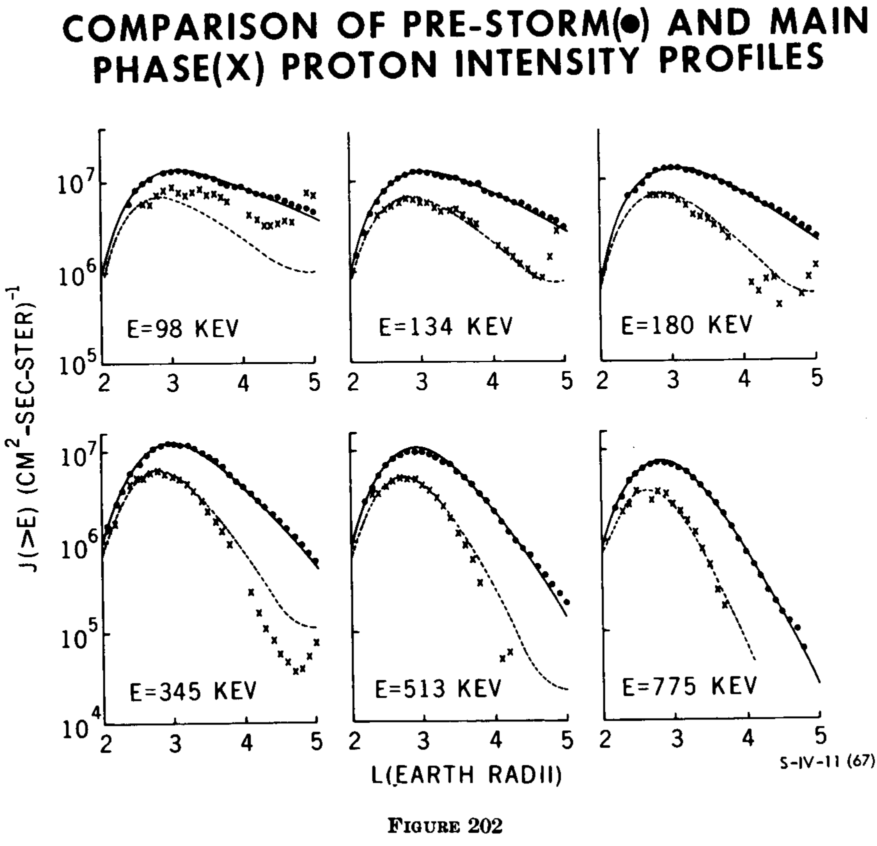

FIGURE 202

tion belt that we may follow their behavior for some time thereafter, and thus learn about the mechanisms by which the radiation belts change in time. This experiment would be a follow-on to the unexpected result of the Starfish test of 1962, but done this time under very carefully controlled conditions. It is demonstrated qualitatively in figure 203.

We would like also to study the formation of auroras by studying what happens if one puts in what we think are the necessary particles and tries to make one. Figure 204 shows the general idea.

We intend to fly an electron accelerator on a rocket: launch it, turn it around properly, take off the nose cone, turn on the accelerator, and shoot the electrons down on top of the atmosphere. We believe we can make an auroral spot. In fact, with the characteristics of the accelerator that we are going to use, it should be possible to make an aurora as bright as a full Moon.

Another experiment will be to shoot the particles from one hemisphere to another and delineate the actual location of the Earth's magnetic field lines, as shown in figure 205.

PLANETARY MAGNETOSPHERES

Finally, what about the magnetic fields of other planets? What about other planetary magnetospheres? Are there any? We know Jupiter emits copious amounts of radio noise. Synchrotron radiation from trapped radiation belts sounds like a good reason for this. Jupiter is known to have a strong magnetic field. We also know what the strength of the solar wind ought to be there. So the best prediction is that Jupiter should have a magnetosphere like the magnetosphere of the Earth, and it ought to go toward the Sun from the center of the planet to the magnetopause, a distance of 50 Jupiter radii, approximately.

Figure 206 shows trajectories at various distances from Jupiter that might be used to make measurements of this predicted radiation belt. This, of course, is a program that many of us are very anxious to carry out.

The little satellite of Jupiter, Io, as shown, has a very considerable effect on the synchrotron radiation of Jupiter. When Io gets in a particular position, the synchrotron radiation's characteristics change drastically. We don't know the reasons for this phenomenon.

Saturn is the planet most similar to Jupiter. It is nearest in size, it rotates at a similar velocity, and is in general the same kind of planet, having roughly the

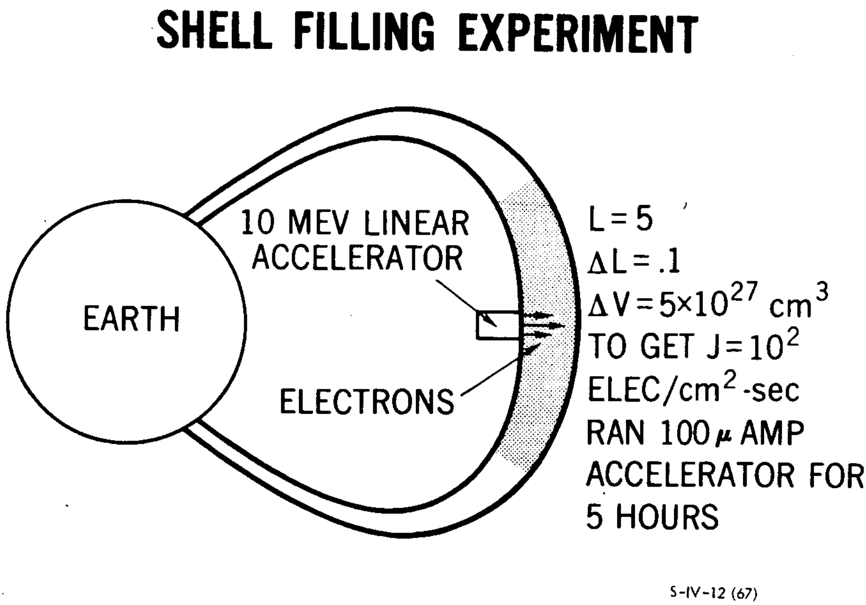

FIGURE 203

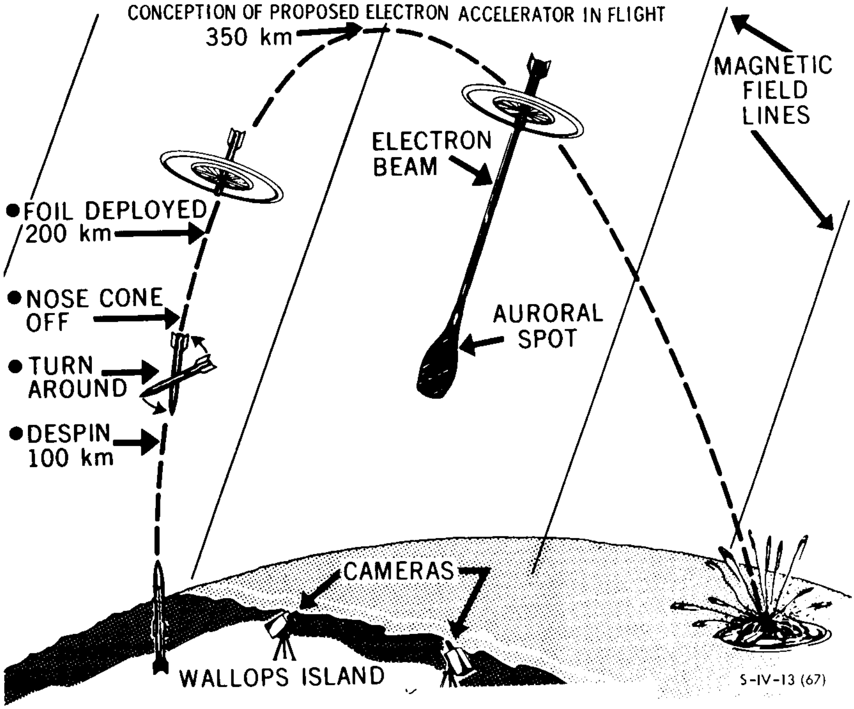

FIGURE 204

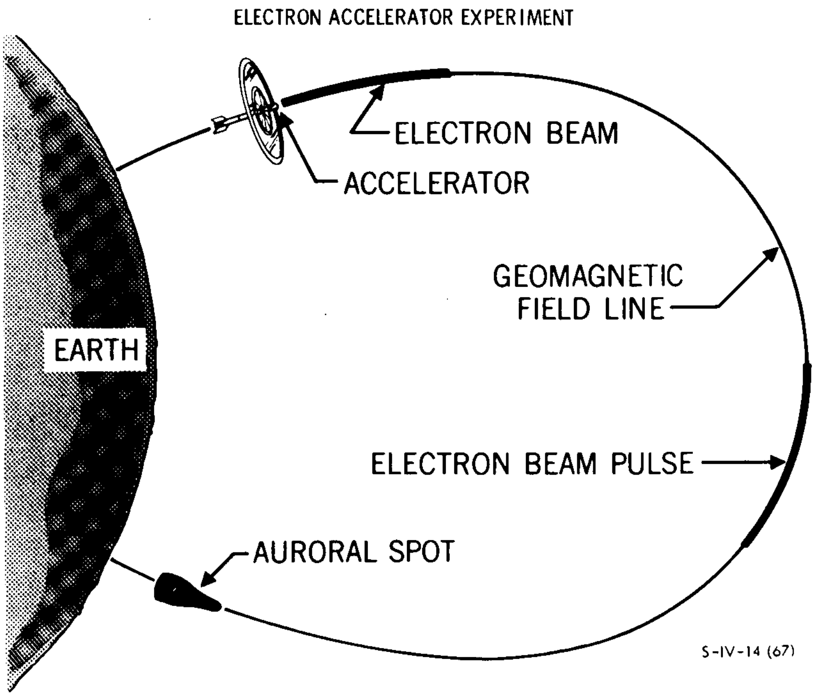

FIGURE 205

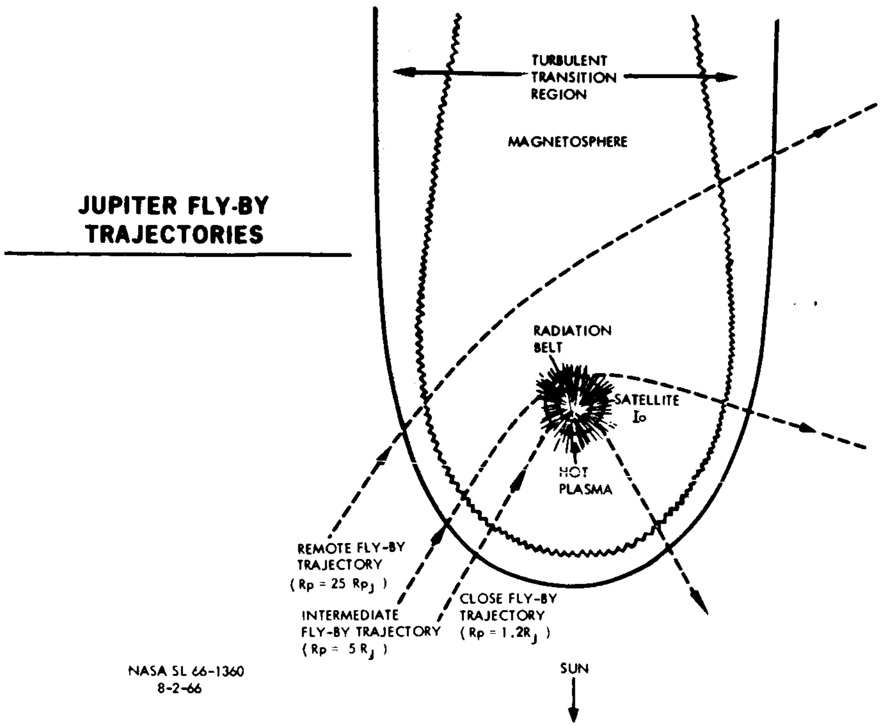

FIGURE 206

same composition and density. It ought to have a magnetic field and probably ought to have synchrotron radiation too. But it doesn't. Why? We don't know the answer to that either.

What about the Moon? Does the Moon have a magnetosphere? Some people think it does. One picture of what the Moon's magnetosphere might be shows it with a magnetopause at the surface and a shock wave about a quarter of a Moon's radius out. If this is correct, the magnetic field and the plasma in the vicinity of the Moon should be different from the field and plasma in ordinary interplanetary space. This would be noticeable when the Moon is outside of the Earth's magnetosphere. Russian measurements on Luna X are not at variance with this idea. The fields and plasma they saw near the Moon did look different from the fields and plasma in interplanetary space. So far none of our luna-anchored spacecraft has carried equipment capable of making this sort of measurement.

CONCLUSION

To conclude, I refer you to figures 196 and 201, the charts with the questions. At this time, most of the "first look" kind of exploratory measurements dealing with the solar wind, the interplanetary medium, and the magnetosphere have been done very successfully.

Through these detailed studies we have an excellent phenomenological picture of our environment out to the interplanetary region. What we don't know in many cases, are the basic physical mechanisms involved. We haven't done the second-generation and the third-generation experiments that are going to tell us why things are happening the way they are happening.

Because of the excellent exploratory results, we are in the position to develop more sophisticated experiments to answer definite questions. This process has already begun and will, I believe, continue well into the next decade.

Finally, we still have before us the exciting prospects of our initial encounters with Jupiter, Saturn and the outer planets, and the necessity to get out of the plane of the ecliptic in order to understand fully the nature of the Earth's environment in space.

APPENDIX V. THE PLANETS

Robert Jastrow,* Director, Institute for Space Studies, Goddard Space Flight Center, NASA, and William Brunk, Program Chief, Planetary Astronomy, Office of Space Science and Applications, National Aeronautics and Space Administration

Nine planets circle the Sun. We inhabit one of them. Two others—Venus and Mars—approach us on occasion as closely as 30 or 40 million miles, which is only a stone's throw on the scale of astronomical distances. Yet, in most respects, we know less about these bodies—the Earth included—than we know about distant stars, tens of trillions of miles away. We do not know how the planets came into existence, nor how the continents and oceans on Earth, for example, were formed; nor of what materials the interiors of the Earth and other planets are composed (the materials in the Earth's crust are known, but there is strong evidence that the interior of the Earth is very different).

More is known about stars than planets for two reasons.

First, a star is a self-luminous body which radiates copious amounts of light. The analysis of the wavelengths contained in this light tells us the composition of the star's surface layer. In some stars, there is enough turbulence—enough mixing and churning inside the star—so that we can assume that the light coming from the surface of the star represents, in its spectrum, the composition of a fraction of the star's interior.

Second, and even more important, stars of every different age are in the sky. We see stars in the process of formation, stars that are young, middle-aged, old and nearly extinct. In the last few decades, by a study of these stars, we have learned the complete life cycle of a stellar body.

But the skies do not reveal the past history of the planets. Every planet in the solar system has closely the same age—4.5 billion years, give or take a few hundred million years. It is very difficult to find out what conditions were like on the planets in their early years. At the present time planetary science is in a more primitive state than astrophysics. It is even difficult to find out which conditions were on the Earth when it was a young planet, although those conditions are of keen interest because they influence modern ideas on the origin of life on the Earth. There is evidence that life began on the Earth in the first billion years of its existence, but *under what conditions did it arise?* We do not know.

Explorations of the Moon, Venus and Mars bring us to the threshold of a new era in planetary science. Those bodies are the same age as the Earth,[1] and a knowledge of their present state will not immediately reveal the past of the Earth, but carefully designed planetary experiments, analyzed by scientists with a broad understanding of the Earth as a planet, may tell us much. The initial flights to the Moon, Venus and Mars have already revealed vitally significant information about these bodies.

Let us present what can be said, at the moment, about the planets and their history, mentioning a few critical spacecraft results as they fit into the discussion. We start from the Sun and go outward in a quick review of planetary properties.

MERCURY

The planet nearest the Sun is Mercury. It is about a third the diameter of the Earth, and is only slightly larger than the Moon. Mercury has an average density of about five, somewhat about the same as the Earth's average density. The length of its year is 88 days and it was thought to rotate on its axis with the same period. Recent radar observations have shown that it rotates on its axis in 59 days, which is two-thirds of its orbital period. It was always thought to be a body without an atmosphere, because of the great heat absorbed by the side that faces the Sun. But there are some indirect suggestions that it has in

[1] One recent theory proposes that the Moon is younger—perhaps less than a billion years old—but this is a minority view.

fact an atmosphere, perhaps as dense as that on Mars, i.e., a few tenths of a percent of the atmosphere on the Earth.

VENUS

Beyond Mercury lies Venus, which is of special interest because it is, or should be, a sister planet to the Earth. Venus, when compared with Earth, has 80 percent of our mass; 95 percent of our diameter; and about the same force of gravity. The length of its year is 229 days. It rotates very slowly on its axis with a period of 247 days in a direction opposite to that of the Earth. (Venus and some of the moons of the major planets are the only bodies that do this.)

The atmosphere of Venus presents an enigma because it is so opaque and extensive compared with the Earth's. The atmosphere is dense and contains particles of some material with high reflecting power. The most reliable measurements of depth of the atmosphere have been made during occultation of stars by Venus. Values from 90 to 120 km have been obtained for the altitude of the cloud tops. (Highest values for Earth are noctilucent clouds at 85 km.)

The composition is obscure; carbon dioxide has been positively identified and formerly was considered a major constituent. We now believe it to be a minor component, probably less than 10 percent. CO and H_2O have also been detected but nitrogen is assumed to be the major component. Only trace amounts of N_2O, CH_4, C_2H_4, C_2H_6, or NH_3 could be present. Based on present theories of evolution of atmospheres, it does not appear reasonable that Venus has retained its original atmosphere.

Venus was always thought to be a very promising body for the discovery of extraterrestrial life, because a calculation of the average surface temperature on Venus—using theories developed for calculating the temperature distribution on the surface of the Earth, and resting on the fact that Venus is 23 million miles closer to the Sun and therefore receives twice as much intensity of sunlight—yields the result that the global average surface temperature is 80° F. This is also the average temperature of the islands in the Caribbean. Venus has a very balmy climate, in principle.

These illusions were shattered by the radio astronomers in 1956, and the destruction was completed in 1962 by the Mariner II spacecraft. The radio astronomy and spacecraft data indicated that the intensity of microwave radiation from Venus corresponds to a body which is above the melting point of lead—about 800° F—and furthermore, that this radiation most probably comes from the surface of the planet and not from its atmosphere, as had been suggested by some observers.

Eight hundred degrees is much too hot to allow the possibility of the development of life, except perhaps at the poles, and that is uncertain. But why is the surface of Venus so hot? The current view is that if Venus is indeed as hot as this evidence suggests, the heat is probably the result of a very dense atmosphere.

Estimates for the atmospheric pressure at the surface vary from about 3 to 300 Earth atmospheres with the most probable acceptable values being from 10 to 100. Estimates of pressure at the cloud tops vary from 1/10 to one Earth atmosphere. Carbon dioxide and water vapor in the atmosphere absorb heat radiated by the planet strongly in some regions of the far infrared spectrum. In the case of the Earth, most of that heat escapes to space. But in the case of Venus, with its large amount of carbon dioxide and water vapor to absorb this planetary radiation, the heat is trapped and returned to the surface, raising the temperature of the surface considerably above the level it would have been if Venus were an airless body of rock. This heating process is called the "greenhouse effect."

Theoretical studies indicate that if the carbon dioxide and water vapor absorption bands are spread out by the pressure broadening, i.e., by collisions in a dense atmosphere, the whole infrared region will become uniformly absorbing, and almost all of the planetary radiation will be trapped and returned to the surface of the planet. Conceivably, the high temperature of Venus has this explanation.

Recently a suggestion was made that all or a part of the microwave emission actually results from electrical discharges in the tops of the Venus clouds. There is a dispute over this suggestion; the spacecraft evidence is against it. But the topic is not closed yet.

We would know more about Venus, which is our nearest planetary neighbor, if it were not covered by the heavy, uniform layer of white clouds, which may be seen in the attached photograph (fig. 207) of Venus taken from the Earth. (The photo shows Venus in the crescent phase, between the Earth and the Sun, with only a part of its illuminated surface visible to us. We see the "full Venus" when it is on the other side of the solar system from us.)

However, it is no longer certain that the Venus cloud cover is complete. Dr. Ichtiaque Rasool of the Goddard Institute for Space Studies points out that the picture of the Earth taken from the Moon by Lunar Orbiter I would look just like the picture of Venus from the Earth, if the Orbiter picture were as badly blurred as the picture of Venus is (by distorting effects of the Earth's atmosphere). It may be that when television cameras are carried to the vicinity of Venus, we will find out that the planet does have breaks in its cloud cover, permitting us to photograph the surface.

Although we have accumulated some experimental data relating to Venus from Earth-based telescopic observations and from the Mariner II fly-by, our present difficulty is that there is a wide range of theoretical models involving CO_2 pressure, cloud particle composition and size, water content, etc., that would account for the atmosphere. We do not know the composition of the clouds. It is interesting to note that the amount of H_2O vapor detected corresponds to that amount in the Earth's atmosphere at high cirrus cloud top levels or approximately 10 miles altitude. However, we have no reasonable accurate value for the thickness of the cloud layer on Venus or the altitude of the cloud tops.

Largely from lack of chemical information, little is known about the clouds. In this connection, some recent data obtained by Connes and analyzed by Kaplan are of considerable interest. Hydrogen chloride has been identified positively as a trace component in the atmosphere. Hydrogen chloride is a highly soluble gas which forms hydrochloric acid when dissolved in water. The industrial grade is

VENUS IN CRESCENT PHASE

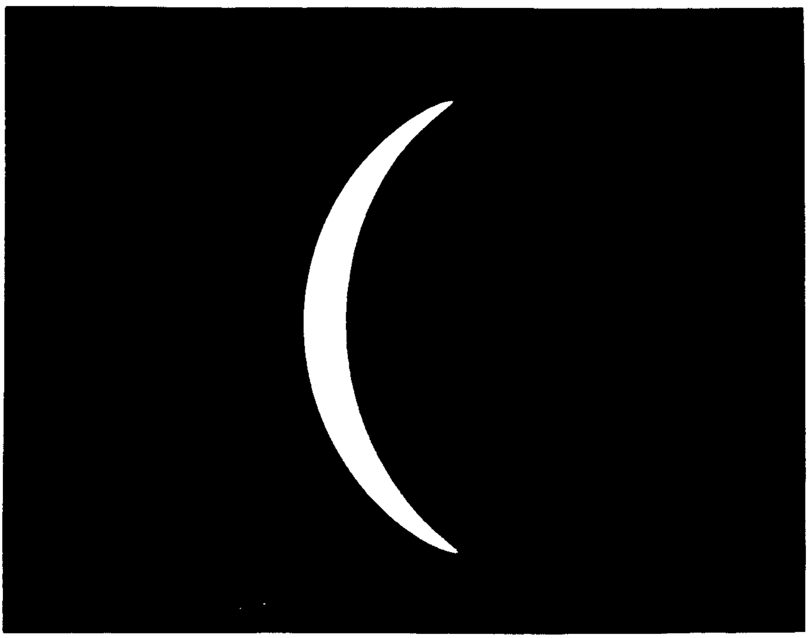

FIGURE 207

often called muriatic acid. It is also interesting to see that not only were several absorptions for HCl found at their proper spectral positions, but HCl molecules with the two different isotopes of chlorine 35, and 37, were also detected.

We know so little about the atmosphere of Venus that we will not discuss circulation movements or surface winds except to point out that, at times, distinctive features can be seen in the Venus cloud cover when examined in the near ultraviolet. These features show movement and travel as if they were part of some kind of atmospheric circulation phenomenon.

How much water is on Venus? The Earth has about 2 kilometers of water in liquid form, on the average, if spread over the surface of the globe. This water is believed to have been exhaled from the crust, in fissures and volcanic activity, during the 4.5 billion years of our history. It is the water that was trapped in the interior of the Earth and gradually came up to the surface. Venus is our sister planet; it should have a similar supply of water trapped in its interior and gradually released to the surface. The best evidence is that Venus has no more than a few centimeters of water, compared with a water layer several kilometers thick on the Earth. (Of course the water would be in the form of a vapor at the high temperature of Venus.) It does not have the copious amount of water (in vapor form in the atmosphere) that we have in liquid form in the oceans.

It is not known why the water seems to have disappeared from Venus. And it is not known why the atmosphere is so much denser than ours. When these questions are answered, we will also illuminate some of the present uncertainties regarding the history of our own planet. At present it can only be said that by terrestrial standards, Venus appears to be a hot, dry planet, unlike the Earth, and very unsuitable for the development of life.

MARS

Skipping the Earth, we come to Mars, which is about 50 million miles farther from the Sun than the Earth is. It rotates on its axis once every 24 hours and 37 minutes, and it circles the Sun every 20 months.

The density of Mars, like that of Venus, is about the same as the density of the rocks lying on the surface of the Earth; for this reason Mars is believed to be composed of rocky materials similar to those on our planet.

The most important new data were obtained by Mariner IV during its July 1965 flyby. The results showed that the pressure, temperature, density, and scale height near the surface were lower than previously supposed. These results were generally supported by the expanded program of telescopic observations that were conducted for that opposition.

The range of surface temperature of Mars is very large. The diurnal variation can be as much as 180° to 270° F. Mariner IV determined a temperature of about —130° F. for the southern hemisphere in the winter and about —58° F. for the northern hemisphere summer value. These temperatures were lower than those previously obtained by infrared measurements but did agree more closely with microwave temperature results.

The presently accepted range of atmospheric surface pressure of 5 to 8 millibars for Mars is in the neighborhood of ½ to 1 percent of the Earth's atmosphere at sea level. The average value for pressure of the Earth's atmosphere at 100,000 feet is about 10 millibars.

The upper atmosphere appears to be colder than previously assumed, a factor important to determining orbit and estimating lifetime for an orbiting spacecraft about Mars. This is because a colder atmosphere would cling closer to the planet and be less dense at high altitudes.

Another property of the Martian atmosphere of great interest is the nature of the circulation of the atmosphere. The yellow clouds, which are believed to be gigantic dust storms, have been studied. Due to the low surface pressure on Mars, large wind velocities are necessary to sweep dust particles from the surface, values of 300 kilometers per hour being typical. These values are much higher than observed for the motion of the yellow clouds, but the data can be reconciled if one assumes the dust clouds represent cyclonic systems on a large scale similar to dust devils observed on our western desert land. This is a reasonable assumption; however, it does not give us any information on the values of wind velocities.

Although these dust storms and haze occasionally are conspicuous, most of the time the face of the planet is open to photographic surveillance. In spite

of the lack of permanent clouds over Mars, it is impossible to obtain good photographs of the planet from telescopes on the Earth because of the blurring effect of the Earth's atmosphere on rays of light reaching us from space. No features of the surface of Mars can be seen from the Earth (no matter how large the telescope in which the planet is viewed) unless they are 50 miles or more in diameter. It is impossible to tell from the Earth whether Mars has mountains, ocean beds, or any features which might indicate the presence of life.

Far better pictures of Mars were taken for the first time by the Mariner IV spacecraft in 1965, as it swept past the planet at a distance of 4,000 miles. The Mariner photographs reveal features as small as two miles in diameter, which is approximately the same degree of detail visible in pictures of the Moon taken from the Earth. The Mariner photographs showed an important point about Mars, namely that it has preserved the record of its past better than the Earth has. Erosion on the Earth, mainly by running water but also by winds, combined with extensive geologic activity, has moved surface materials from one place to another and churned them over in a time scale of 10 to 50 million years. Events which occurred earlier than that are not directly detectable. Most meteorite craters have been eroded away; only the most recent, such as the Arizona crater, are still clearly visible.

In the case of Mars, the Mariner photograph reveals a density of craters which is about the same as that on the Moon. The density of craters on the Moon is consistent with the idea that it has been peppered by meteorites since the solar system was first formed. It makes the Moon very interesting to the student of the origin of the solar system, because it has preserved its history going right back to the beginning of the solar system, a history lost to us on the Earth.

The well-preserved state of the Mars craters suggests that Mars, like the Moon, has not been strongly affected by erosion of wind and running water.

However, there are those who point out that Mars is closer to the asteroid belt, which is thought to be the source of most meteorites, and perhaps more heavily peppered by meteorites than the Moon and the Earth have been; therefore, firm conclusions cannot be drawn from the number of craters that the Mariner photograph revealed.

But it seems that the surface of Mars, while perhaps not as old as that of the Moon, is certainly older than that of the Earth; it is a surface which may be of the order of a billion years old.

The Mariner photographs, by the way, did *not* reveal signs, within their limited resolution, of a past history on Mars in which there was an extensive amount of running water. That fact has a bearing on the origin of life. Oxygen is not needed for life, but water is necessary. One needs a fluid medium in which molecules—the basic building blocks of life—can collide, and chemical reactions go on.

Mars may be relatively arid now, but may have had more water at an earlier point in its history. If so—if water existed there for a hundred million or a billion years—life may have developed and then declined. But there is no trace of erosion by running water in the Mariner photographs obtained thus far. Thus, it looks as though for a considerable period in the past Mars has been a relatively dry planet.

The Mariner photograph had a resolution of about two miles. A future flight is planned to have a resolution ten times better, and may illuminate the interesting question of water on Mars in its past history.

Until several years ago, there was much interest attached to interpretations of the Sinton bands. Infrared spectra of Mars reported by Dr. Sinton in 1959 showed indications of molecules with carbon to hydrogen bonding. This was of tremendous interest because bonds of this type are shown by all living material and essentially all organic compounds. However, these spectral features were later shown to be due to heavy water vapor HDO in the Earth's atmosphere. A recent finding of great interest is the identification of CH_3X (substituted methane) in the atmosphere of Mars by Kaplan who interpreted spectra obtained by Connes.

ASTEROIDS

Beyond Mars there is a large gap in the distribution of the planets. Bode's law predicts a planetary body located outside the orbit of Mars at about three times the Earth's distance from the Sun; but instead we find only a large number of small bodies circling in a ring. These are called *asteroids*. Occasionally, collisions between these bodies, or perhaps, the gravitational pull of Jupiter, will pull

one of them out of its orbit and into a collision course with the Earth. It is believed that many, if not all, of the meteorites which hit the Earth have this origin. Examination of the meteorites which survive the searing passage through the Earth's atmosphere reveals them to be pieces of rock and iron with a rather complex physical and chemical history. Many of these meteorites appear to have been pulverized at some point in their early history and compacted again into their present form. All this evidence together suggests that there may once have been a group of planetesimals of substantial size in an orbit between Mars and Jupiter. For some reason, the planetesimals did not reach the ultimate stage or accumulation into a large-sized planetary body, as did the other objects in the solar system; or, if they did, they were disintegrated again in some subsequent catastrophe. Their total mass is only one thousandth of the mass of the Earth; that is not really a respectable mass for the fragments of an entire planet, a fact which deepens the mystery of the asteroids.

Beyond the asteroids a planet is located where we next expect to find one. It is called Jupiter. Jupiter is the first of the Major Planets, the others being Saturn, Uranus and Neptune. All are of a type completely different from the Earth and Earth-like planets discussed up to this point.

PLUTO

Beyond the Major Planets, finally, is the small planet Pluto, discovered in 1931, which is the ninth and last planet to be found in the solar system. Practically nothing is known about Pluto. From the amount of light it reflects, it is probably about the size of the Earth; we know its mass from planetary perturbations in its orbit; from these two results we deduce that it has the density of the Earth. It is probably an Earth-like planet composed of rocky materials; but, of course, it is a frozen silent world, far too cold to support any form of life.

MAJOR PLANETS

More is known about the Major Planets. They are approximately ten times larger in diameter than the Earth and 100 times more massive, but considerably lower in density.

The Major Planets are less dense than the Earth and its neighbors because they are made up largely of the lightest elements, hydrogen and helium. These elements make up most of the matter in the universe, about 99 percent as far as is known. They also make up 98 or 99 percent of the elements in the cloud of gas and dust around the Sun out of which the planets formed.

If, as is commonly believed, all the planets formed around the Sun as minor condensations under the force of their own gravity, in the same way the Sun itself was formed, that composition should be similar to that of the Sun. In other words, they should look like the Major Planets; they should not look like terrestrial planets.

These Major Planets, because they have the full abundance of the light elements, hydrogen and helium, are very much less dense than the terrestrial planets. The terrestrial planets have the density of rock, which is three grams per cubic centimeter. More precisely, depending on how big they are and how much they are compressed by their own weight, their density varies from three to five grams per cubic centimeter.

The Major Planets all have a density in the neighborhood of one gram per cubic centimeter, which is the density of water. Saturn, in fact, has a density of 0.7; it is less dense than water, and would float in a bathtub if you could get it in.

JUPITER

Jupiter is the largest of the Major Planets and the largest planet in the solar system, eleven times larger in diameter than the Earth and 318 times more massive.

Jupiter is characterized by the famous red spot which has attracted the interest of astronomers for two hundred years. The spot varies in visibility in an irregular manner over periods of several years, changing from a hardly visible faint pink to a fairly conspicuous red. The atmosphere also shows bands and zones of varied colors. Although many interesting suggestions have been made to account for these features, identification of the composition remains as a challenge to future space missions.

Jupiter is within a factor of thirty of being massive enough to be a star. If Jupiter were thirty times more massive, the pressures and temperatures at its center, produced by its own weight pressing on its interior, would rise to the threshold for ignition and burning of nuclear fuel, which would make it a star. It fails to make the grade; if it did our solar system would be a double star.

This brings us to one of the highlights of recent planetary research. Dr. Frank Low, a physicist turned astronomer, has been working in infrared astronomy, which is one of the most exciting and profitable new fields in astronomy. He has measured the infrared energy emitted from Jupiter, and has discovered that the planet is radiating to space *four times as much energy as it gets from the Sun.* What is the source of this extra energy? Is it nuclear? The theoretical astrophysicists state that Jupiter is too small to burn nuclear fuel at its center. Probably they are right, for the missing factor of thirty in mass is significant. Is there another explanation? Perhaps Jupiter gained much energy when it first condensed, out of the solar nebula, as parts of itself fell on one another under the force of their gravitational attraction, and the planet was heated to so high a level that it is still releasing to space the remanent of that primordial gravitational heat. We do not know. We can only say that this result in infrared astronomy is one of the most interesting planetary observations obtained in the last year.

Can there be life on Jupiter? At first thought it seems that Jupiter is a very poor place for the evolution of life. The planet is far from the Sun, and its temperature, as measured at the tops of the clouds, is a frigid 300° F. below zero. But we must remember that below the cloud tops the temperature, by basic laws of physics, must rise, just as the temperature of the Earth's atmosphere rises from 50° F. below zero at the cloud-top altitude of 30,000 feet, until as one descends toward the ground it reaches an average temperature of 60° F.

The temperature on Jupiter also must rise below the cloud tops, and calculations indicate that at some point in the atmosphere, or on the surface—if the planet has a surface—it will pass through a regime which is suitable for the support of life.

Further, we know that Jupiter has an abundant amount of the atmospheric gases which are believed, according to the Haldane-Oparin-Urey theory of the origin of life, to be necessary for the development of life. These gases are hydrogen, methane, ammonia, and water vapor; they are copious in the Jovian atmosphere, and we wonder whether perhaps the chemical evolution of life has started there, at some level below the cloud tops.

Conditions on Jupiter are so different from those on the Earth that we cannot even guess at the form such life might assume. We will not know for a long time, not until spacecraft have made the five-year roundtrip to that planet—and that is many years off.

SATURN

The planet Saturn also presents interesting questions. The methane-to-ammonia ratio in the upper atmosphere is much higher than it is for Jupiter. The atmosphere also shows banding and cloud variations but, on the whole, does not appear to be as active as that of Jupiter. Saturn and Jupiter are of great interest because they may still have their original primitive atmosphere.

PLANETARY UNKNOWNS

With this short synopsis of the planets, I would now like to bring out some of the reasons scientists of many different disciplines are excited about planetary studies.

Does Mars have a primitive atmosphere similar to the one for the primeval Earth? Does the failure to find evidence of primitive volcanic gases in noticeable concentration indicate much less volcanism has occurred than for the Earth? Or has Mars already lost its secondary atmosphere?

How has the massive atmosphere of Venus arisen? There must have been unique processes of unknown nature to provide an Earth-like planet with such a considerable atmosphere compared to Earth and Mars. Could Venus have now or have developed and lost indigenous life, a life with processes attuned to an environment so different that we are unable to speculate upon its form?

The outer planets are cold, and their atmospheres fit well into our theories of planetary evolution. Mars, Venus, and the Earth when examined as sister planets present important problems we cannot explain.

EARTH

Let us now say something about recent developments related to the history of the Earth and its atmosphere. These developments have a strong influence on the current views of biochemists regarding the origin of life on the Earth.

When the Earth was first formed, it must have been very warm, or else it became very warm at some point shortly after its formation. We are certain of this because at the very beginning the Earth must have consisted of rock-like materials with bits of iron and nickel—which are abundant elements—sprinkled throughout its interior. At the present time, most of the iron and nickel in the Earth exist in the form of a molten core at its center. The solid rock mantle surrounds this core; capping the mantle is a thin crust of lighter rocks forming the continents and ocean basins (fig. 208). Apparently the Earth became hot enough—either by radioactive heating or by the heat acquired when it first gathered together under the force of its own gravity—so that the iron and nickel which were sprinkled throughout the body of the planet melted and ran to the center.

In this same early period of the Earth's history, it lost its primitive atmosphere; perhaps the atmosphere was evaporated by the same heating processes which melted the iron within the Earth, or perhaps it disappeared for another reason. Why are we certain that the primitive atmosphere is gone? There are particular gases—rare gases, neon, argon, and xenon—which should be present in the Earth's atmosphere in their full primitive abundance, because they are too heavy to escape the Earth's gravity, and are too inert chemically to enter into combination with other substances in the crust. Nonetheless, these rare gases are present in only trace amounts. Of neon, for example, there is present only one-tenth billionths as much as should be had. If the Earth had its primitive atmosphere, it would have the expected abundance of neon.

The present atmosphere of the Earth, we are therefore forced to conclude, has been acquired in the same way as the water of the oceans, namely by the exhal-

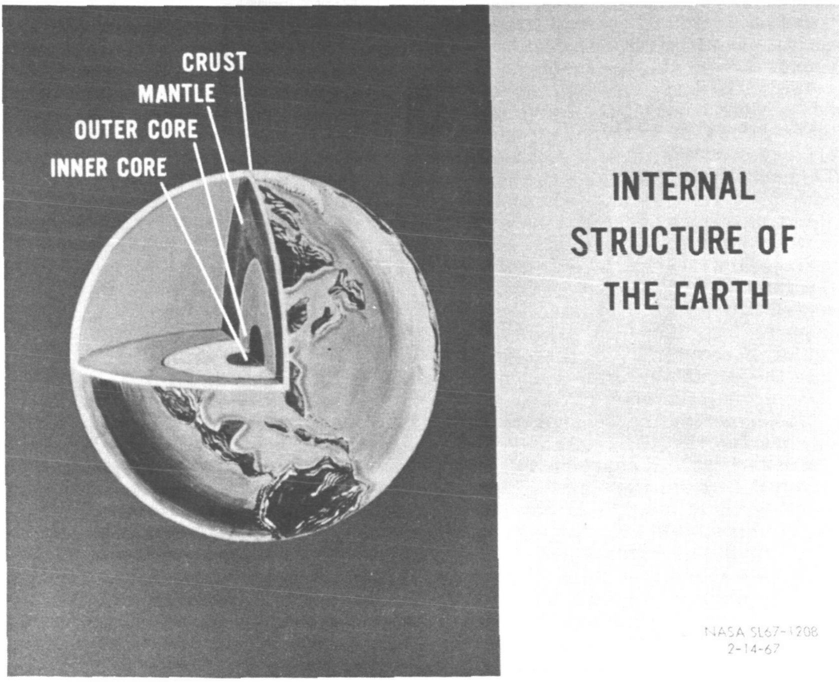

FIGURE 208

ing of gases in volcanic activity. Pursuit of these studies represents one of the most interesting areas for further work in planetary science.

APPENDIX VI. PLANETOLOGY

Verl R. Wilmarth, Chief of Planetology, Office of Space Science and Applications, National Aeronautics and Space Administration

Planetology is planetary geology. It is a science that dates from the early 17th century when the words cosmology and geology were used interchangeably to refer to the study of the natural phenomena on and in the Earth. The science of planetology since then has broadened in scope and today is defined as the study of the condensed material in the solar system, excluding the Sun. Thus, it includes study of the planets (including Earth), the Moon, planetary satellites, asteroids, comets and meteorites. It is concerned with the origin, composition, nature and distribution of matter within these solid objects and with the forces that control them. The evolution of ancient life forms as well as large scale climate variations are of interest to planetologists. In this respect, bioscientists and planetary physicists are co-workers with the planetologists. Astronomers provide the techniques for the planetologists to study the solid objects of the solar system from the Earth. Today, primary interest is in the Earth as a planet, the Moon, meteorites, the nearby terrestrial planets—Venus, and Mars, as well as Mercury and Jupiter.

We would like to know more about the differences and similarities between the Moon, the Earth and adjacent planets; does the Moon, like the Earth, have internal structure? What is the nature and origin of the craters we know occur on the Moon and Mars? Were they formed by meteorite impact, such as we believe was the origin of Meteor Crater in Arizona? What are the composition and distribution of the rocks? Are the rocks observed at close range by the Surveyor spacecraft cameras, as old as 4.5 billion years, the age of the oldest rocks on Earth? These and many more thought-provoking questions have faced Earth scientists for decades; yet, for most, complete answers have not been found, nor can they be found without exploring other bodies in the solar system.

With the Earth as a planet, let us consider the methods planetary geologists use in their study of the Earth. Evidence is obtained by direct measurements or observations, from secondary measurements by geophysical techniques, by laboratory investigations on rocks and minerals, and by comparative investigations. This last method provides us the means of gaining an understanding of the solid body properties of the Moon and nearby planets.

Let us review what can be said about the Earth as a planet. Man's innate curiosity has resulted in the accumulation of libraries of information on the surface and near-surface features of the Earth. Yet our direct knowledge of the interior and the processes that formed the Earth is meager. Man has observed directly to depths of less than 2 miles in mines and by means of drill holes to less than 5 miles, or a very small fraction of the 4,000 miles to the center of the Earth. Furthermore, man may never be able to make a hole deep into the Earth's interior and must rely on indirect evidence for knowledge of the internal characteristics.

Geophysicists and seismologists study earthquake waves to learn about the Earth's interior. In 1909, they determined that the bottom of the crust was characterized by a sharp change in the velocity of the earthquake waves as they traveled through the Earth. Since then, new data have shown that the Earth is made up of a series of concentric shells (fig. 209). The major ones are the crust, the mantle, and the core. The thin crust is underlain by the mantle, a thick shell that extends downward about 1800 miles. The core beneath has a radius of about 2,100 miles. The crust and upper part of the mantle are known to vary markedly in physical and chemical properties. These concepts may change as we increase our knowledge, just as we once assumed that the ocean floors were largely featureless until depth soundings uncovered the Mid-Atlantic Ridge and numerous other submarine mountains and trenches.

The crust is believed to average about 6 miles thick under the ocean basins and increases to as much as 35 miles under mountainous regions such as the Sierra Nevada in California. Based on the present theories of mass distribution and gravitational behavior, the Earth has an average density of 5.5 grams per cubic centimeter; by direct measurement we know that its surface rocks average

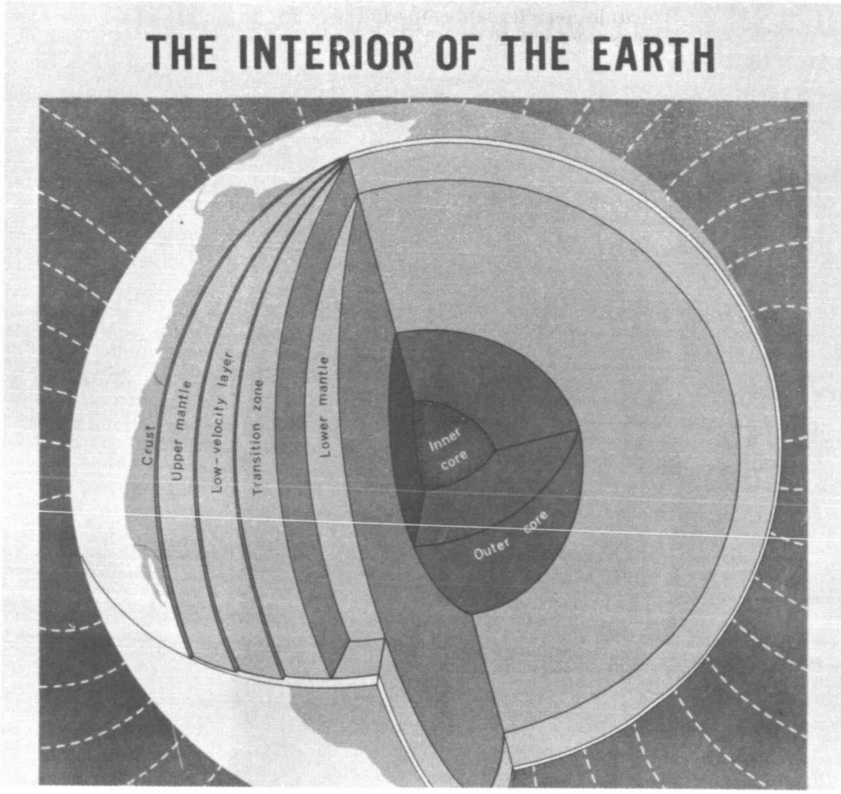

FIGURE 209

2.8 grams per cubic centimeter. Because of this difference, a large mass of heavy material must lie below. We infer from these and other data that the Earth has a heavy central core. Figure 210 shows an estimate of the density distribution within the Earth. The core has about the same density as iron.

Knowledge of the distribution and composition of the rocks that make up the crust has been derived largely from field geologic studies and laboratory analysis of rocks of the continents and limited areas of the ocean basins. The crust is believed to consist of an upper layer of granitic rocks and a lower layer of more dense basaltic rocks. Under the oceans, the crust is basalt, whereas granite rocks form the continents. The crustal rocks are largely made up of 8 major elements of which oxygen atoms make up more than 60 percent (fig. 211). This suggests that we are walking on a platform which is predominantly oxygen.

Meteorites are the only extraterrestrial material we have for comparative study with Earth data. They are space probes that record events that have occurred during the past 5 billion years. They differ in mineralogy, texture, and composition from terrestrial materials and reveal complex histories of space erosion, breakup, and radiation. Some meteorites have an average composition similar to that of the crust (see fig. 211) whereas others are principally nickel and iron; still others are rich in carbonaceous material. We can infer from these data that the source of some meteorites must be similar in elemental composition to that of the Earth. The source of meteorites is not known although some are thought to come from the asteroid belt, and others from spent comets. Perhaps the first lunar sample will help answer this question.

Our study of meteorites has resulted in development of new analytical techniques and instrumentation. These new methods will find direct application in the analysis of the first lunar samples returned to Earth. Many of these methods, such as electron microprobe analysis, are furthering our knowledge of the origin and evolution of terrestrial materials.

Cartographic and geologic mapping of the Earth are monumental tasks, which have been underway for decades. Since World War II, photogrammetric and

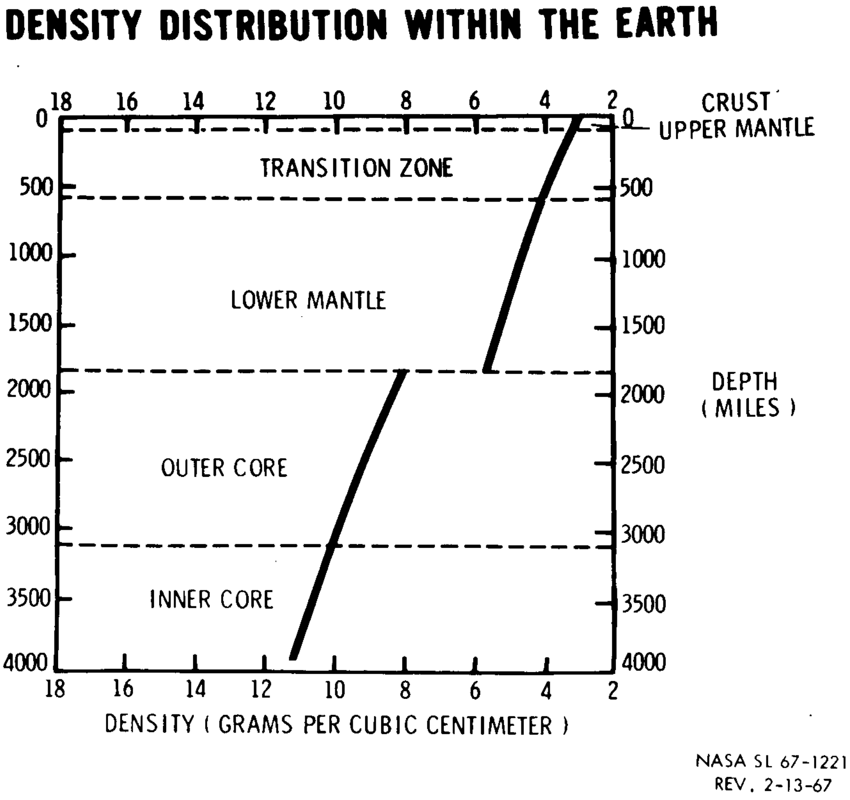

FIGURE 210

photogeologic techniques have aided greatly in systematic mapping of the Earth. However, to date we have useful and reliable maps of less than 40 percent of the land area and only a fraction of a percent for ocean areas. Excellent synoptic photographs from orbiting spacecraft are providing new and exciting means for unraveling geologic problems of large areas of the Earth's surface. This photograph of the Sinai Peninsula area (fig. 212) illustrates the value of these photographs in Earth-bound investigations. From it, the regional relationship of the sea areas (black in this view) to the regional fault pattern can be determined. These data aid in unraveling the geologic history of the area and the nature of the crustal processes.

Orbiting cameras and other remote sensors, such as infrared and radar devices, are extending our knowledge of the forces and processes that change the Earth. They are contributing to Earth-based studies by other agencies and thereby to the solution of such problems as the size and shape of continents and of polar ice caps, the movement of glaciers, and the occurrence and distribution of volcanoes and earthquake areas.

The Moon, some 240,000 miles away, has a diameter about half that of the Earth's core, or about one fourth that of the Earth. Judging from the Moon's calculated average density of 3.3 grams per cubic centimeter, we can hypothesize that its composition is similar to that of the Earth's crust or mantle. Recent spacecraft data indicate the Moon's magnetic field is very small if, indeed, it has a field. This suggests that, if iron is present, it must be dispersed rather than concentrated in a core like the Earth's. Infrared measurements give a lunar sur-

THE COMMONER ELEMENTS IN THE EARTH'S CRUST

ELEMENT	CRUST / ATOM (PER CHART)	METEORITE / ATOM (PER CHART)
OXYGEN	62.55	58.6
SILICON	21.22	16.7
ALUMINUM	6.47	1.5
IRON	1.92	6.3
MAGNESIUM	1.84	14.9
CALCIUM	1.94	1.12
SODIUM	2.64	.77
POTASSIUM	1.42	.08

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FIGURE 211

face temperature range from 220° to 380° Kelvin which is somewhat broader than that found on Earth. This is because the Earth's atmosphere serves as an insulator and moderates the variations.

The Moon has an extremely low atmospheric pressure. An equivalent ultra-high vacuum of about 10^{-12} torr, has only recently been attained in the laboratory; however studies are already underway to measure the effects of this vacuum on rock properties. In 1965, spacecraft landings demonstrated that the lunar surface material was cohesive and could support spacecraft.

It has been theorized that the Moon's age is comparable to that of the Earth. The Moon may, therefore, contain a record of the early solar system events that have been erased from the Earth by erosional processes. The characteristics of lunar rocks may provide clues to the origin and evolution of the Earth, and might be correlated with mountain building and other terrestrial events. Since the 17th century, increase in our knowledge of lunar surface features can be seen by contrasting the drawings shown in figures 213 and 214. The former illustrates Galileo's picture of the Moon, made in 1610, and the latter a recent photo mosaic compiled by the Air Force's Aeronautical Chart and Information Center.

Lunar surface features are well preserved, suggesting that erosional processes like those on the Earth have not been active. Geologic mapping of the Moon has shown that meteoritic impact was an important process in forming lunar surface features. Without an atmosphere, meteors strike the surface at full velocity, forming craters and surrounding adjacent areas with ejecta blankets and rays. This map of the Kepler region shows the large crater Kepler surrounded by its two ejecta blankets, the older one shown in light tone and the

younger in dark gray (fig. 215). To answer questions concerning the nature of the crater mechanism, the size, velocity, etc., of the impacting missile, and characteristics of the impacted surface material, laboratory studies using high velocity guns have been carried out in conjunction with study of man-made craters and meteor craters on Earth. These investigations have provided clues to the flux of meteors on the Moon, data on classification and origin of the lunar craters, and an indication of the possible depth to solid rock below the surface. From the study of the Lunar Orbiter photographs, it has been suggested that the Moon is covered by a layer of loose material, 3 feet thick in some localities. Statistical studies of the size, frequency distribution and characteristics of lunar craters suggest that the Moon has long been saturated by impacting solid objects.

Studies of meteoritic impact craters on Earth and of features found in volcanic areas provide the guidelines for interpreting lunar features. Though meteoritic impact is presumed to be the dominant formative process on the Moon, close-up views of the lunar surface by Lunar Orbiter suggest that volcanic activity has occurred in some areas. This conclusion is supported by the 1964 reported sightings of gaseous emanations from the crater Aristarchus.

Man's landing and analysis of lunar samples returned to Earth will go far to answer fundamental questions concerning the origin of the Moon. Preparatory for the analysis of lunar material, many new analytic techniques and instruments have been developed in the course of investigation of meteorites and tektites, the only extraterrestrial materials available. Because of the necessity to preserve as much as possible of the lunar material, microanalytical techniques

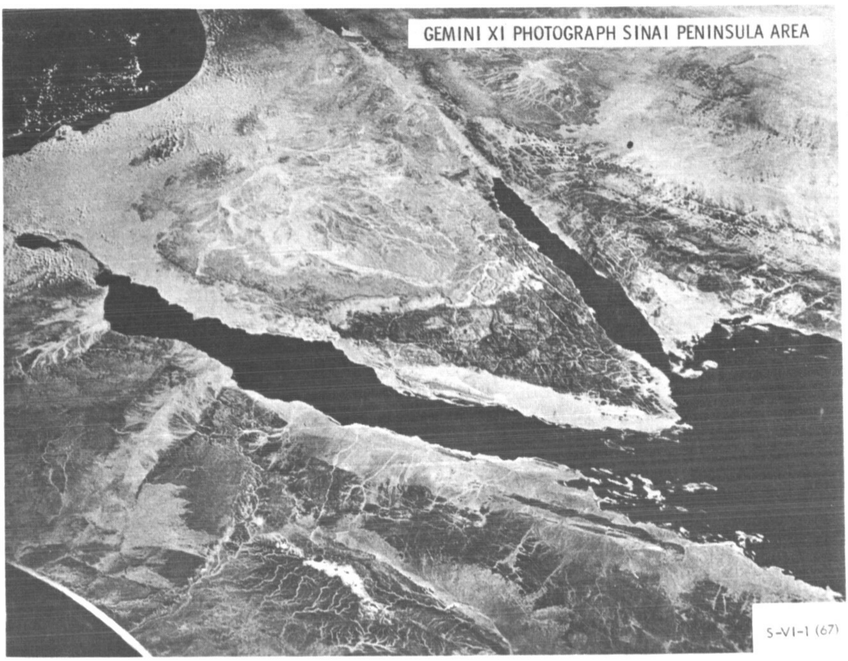


FIGURE 212

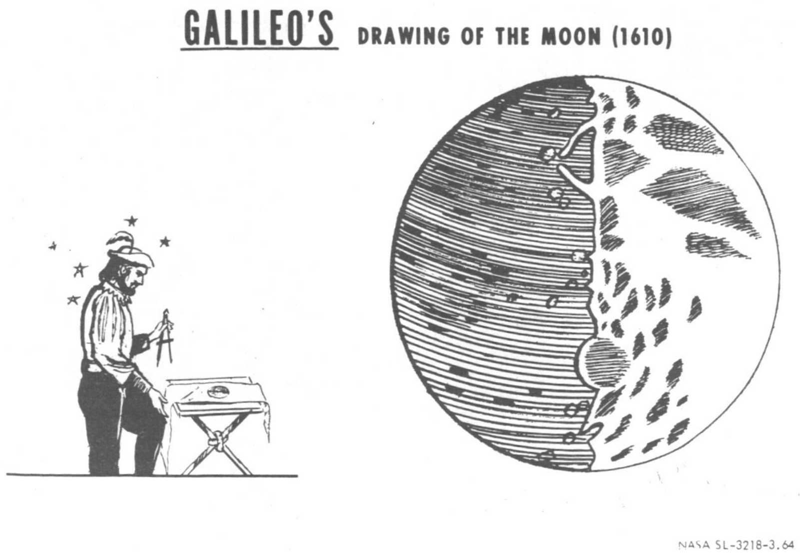


FIGURE 213

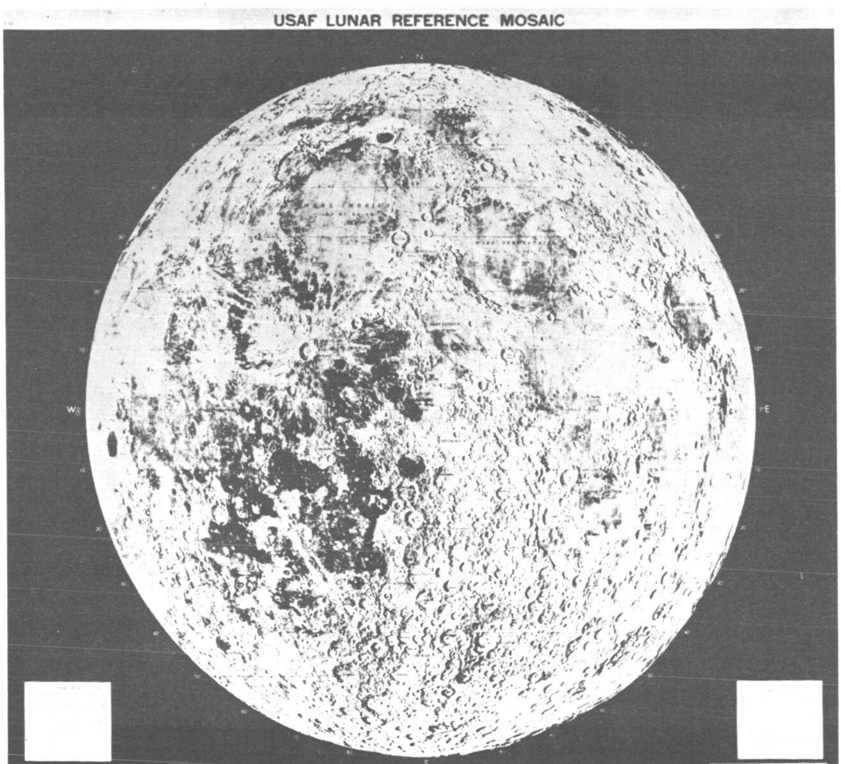


FIGURE 214

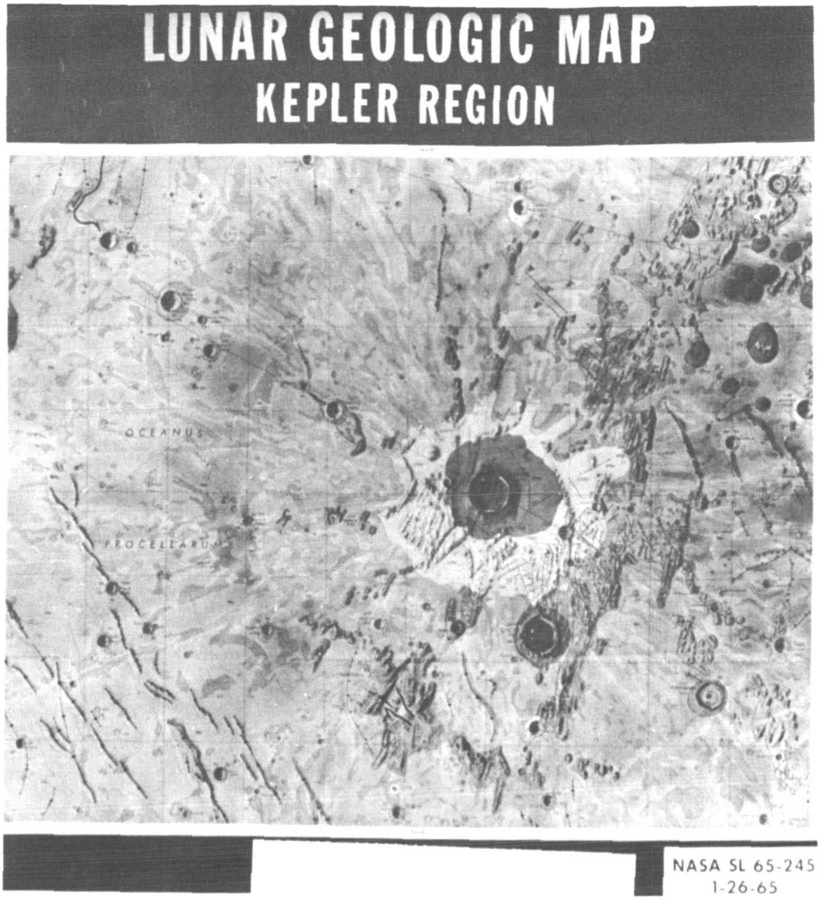


FIGURE 215

such as the electron microprobe were developed and are being applied today in mineralogic and metallurgical studies of Earth materials. Detection of a few parts per million of diagnostic elements in these materials is providing clues in the search for new mineral sources.

The need for lighter, compact, reliable, and sensitive scientific instrumentation and advanced techniques for observation and analysis from spacecraft and on the lunar surface has resulted in new designs and miniaturized instruments such as mass spectrometers, gas chromatographs, differential thermal analyzers, diffractometers, spectrometers, radiometers, radar transmitters and receivers, gravimeters, seismometers, and magnetometers. Many, if not all, of these will find application to Earth problems, including the search for new resources. As an example, the small X-ray diffractometer developed for use on a Surveyor spacecraft to make mineralogic determinations on the lunar surface appears to be more effective than some much larger laboratory instruments currently in use.

Within the next decade, major advances in our understanding of the Moon and its nature will form a sound basis for increasing our knowledge of the Earth, its history, and future.

Appendix VII. Astronomy as a Space Science

Henry J. Smith, Deputy Director of Physics and Astronomy Programs, Office of Space Science and Applications, National Aeronautics and Space Administration

This review of NASA's astronomy program will be oriented towards the objects of astronomy (the bodies of the solar system, the stars and dust of our galaxy, and the universe of galaxies) ; these objects shall all be discussed in terms of the observations astronomers make over the whole range of the radiation spectrum, from the extremes of radio astronomy to space observations of X- and gamma rays. After defining what astronomy is, and restating its well known objectives, we shall examine the relative roles of ground-based and space astronomy observations. We shall also note the contribution of astronomical observations to other space sciences. Then we will examine in some detail some recent accomplishments in astronomical research, before considering the future prospects, and the role that space observations with large telescopes must play in further progress towards achieving our objectives.

To begin this review, it is important to recall the peculiar sense in which we use the term "astronomy" in NASA. An astronomy student in college would normally use a textbook which treats astronomy as a study, by any means whatsoever, of remote astronomical bodies. However, astronomy has been revolutionized by spacecraft which has given us the capability of studying remote astronomical bodies by powerful new ways of research. We can now go to the bodies of the solar system, to retrieve samples, to make *in situ* measurements, and even to make perturbations of those remote bodies and environments to study the resultant effects. Accordingly, we use the term astronomy in NASA, as shown in figure 216 to mean the study of extraterrestrial bodies by their radiations (gamma rays, X-rays, ultraviolet light, visible light, infrared, and radio frequency emissions), using telescopes of one kind or another. Diverse organizational parts of NASA are concerned with the study of the Moon, of the planets, of the Earth's atmosphere, and of the Sun and stars. We shall not emphasize all these applica-

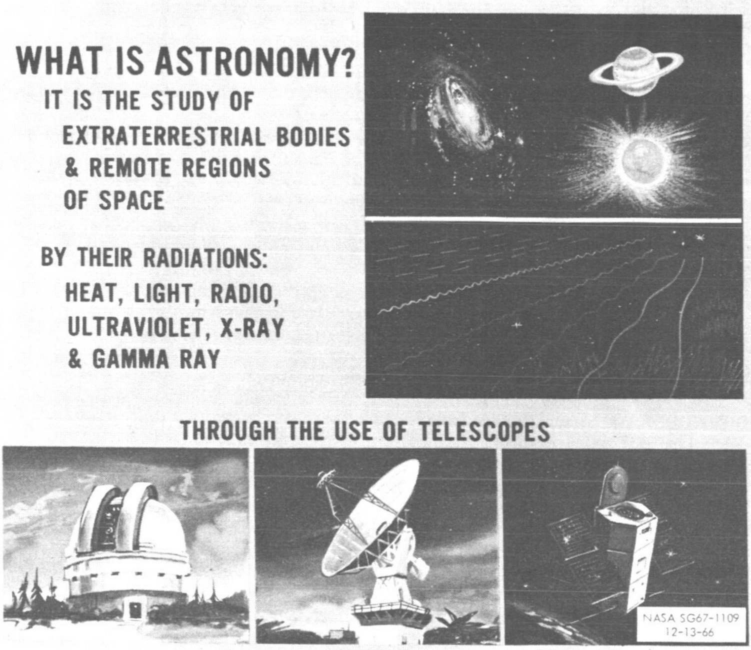


Figure 216

tions of astronomical observations in this review. However, much of what we say would be directly transferable from one to another of these specialized subdisciplines of what used to be simply astronomy.

Astronomy asks and seeks answers to basic questions which nearly all men have asked themselves at one time or another:

What is man's place in the scale of things?
Is the Earth the solitary abode of life in the universe?
What is the past history and future of the Earth?
What is the temporal relation of man's history to the age of the Earth?
What is the age of the Sun? Of the solar system?
What is the age of other possible abodes of life?

The objectives of the discipline of telescopic astronomy are to learn, by remote observations, the structure and behavior, the origin, growth, and demise of all types of celestial bodies, ranging from the smallest (meteorites, comets and planets) to the largest, including stars, star systems, the matter in space, and the entire cosmos.

Of course astronomy is not a young science, but rather one of the oldest branches of human learning, dating back at least 10,000 years. Astronomy can count great accomplishments to its credit. The great names of astronomy are among the foremost discoverers in the whole course of human history, including Kepler, Tycho, Copernicus, Newton, and Gauss in former centuries. The questions that were foremost amongst those astronomers and pursued until a few decades ago have now been answered and today form part of the education of every man:

What is the Earth? The Sun and the Moon? Planets? Comets? Meteors?
Is the Earth flat? Or round? How big?
What is the cause of day and night? Of the yearly variation of seasons? Of eclipses of the Sun and the Moon?
What is a star?
What is the Milky Way?

Now that we have the answers, we recognize how simple the questions were. Yet securing these answers ranks among the great triumphs of human inquiry.

The current questions occupying 20th Century astronomy use a different approach than was possible in former ages. Today we use the laws of physics to learn what we can of remote astronomical objects. These laws of physics are derived partly from the study of astronomical objects themselves, partly from the study of laboratory phenomena, and partly from theory. However, astronomy has always been one of the chief frontiers of science.

By successfully attacking the major questions of astronomy, men have learned many of the basic laws of nature. These triumphs of discovery have enabled man to master his environment, and to appropriate and utilize the natural resources of this planet to create our present way of life. It is trivial to name a few of the obvious examples—*gravity* and *inertia*, which Isaac Newton invented to account for planetary motions; *relativity*, Einstein's contribution to understanding of space and measurement as well as of cosmology; *thermonuclear processes*, first appreciated as the way stars generate energy; and the complex theories of *radiation* and *spectroscopy*, which rank among the most powerful tools of industrial technology as well as of scientific research. In the future astronomy promises to teach us as much of new basic physical laws as it has in the past. It is both source and proof of these laws.

The astronomer today seeks to learn and understand the motions, sizes and compositions of stars; their ages, their structure, and their evolution. He seeks to know the nature and behavior of the stuff between the stars and its relation to the stars. Foremost in our search is to learn more of the processes in the universe, emphasizing the changes in the matter and the states of the stars. In particular, we try to deduce the evolution of individual objects, and even the evolution of the chemical elements, to understand how the average composition of stars and of interstellar matter has varied with the progressive aging of the cosmos. The whole history of the universe is a separate area of inquiry, for only by astronomical observations are we able to get the basic data with which to inquire into the curvature of space, or the expansion of the universe as predicted by the general theories of relativity. Since Einstein's revolutionary first papers, additional theories of relativistic cosmologies have been formulated. The old and the new theories all seek to provide answers to the fundamental philosophical questions: Is the universe infinitely large? Is it infinitely old? Is it eternal?

Telescopic observations of the most remote objects known to man provide one approach to answering these questions. As our space technology matures, we hope to provide additional independent information on cosmological phenomena, for example by testing the theory of relativity with high precision atomic clocks and gyroscopes orbiting in space. Because starlight takes so long to reach us from very remote bodies, observations of them actually give a picture of the universe in the past, i.e., when the rays of light left their source.

Let us now look at the rationale for doing astronomy from the ground, in an age when one can do astronomical observations from spacecraft. It must be clear from the generic questions that one asks in astronomical research that a great many different kinds of observations are needed to achieve the broad objectives. Furthermore, astronomers need long-term observations to inquire into the variability of individual objects like the Sun or variable stars, and to integrate the signals from very faint objects. To observe the very faintest stars even with a 200-inch telescope, the astronomer literally has to wait for the photons to come, one by one, into his photocell. In addition, the astronomer uses a wide variety of techniques of observation requiring specialized telescopes for each technique, and in each narrow wavelength range of the spectrum. The spectrum extends from radio frequencies (with wavelengths measured in hundreds of miles), through the infrared (with wavelengths measured in small fractions of an inch), through visible light, down to the ultraviolet and X-rays (where wavelengths are of the order of atomic dimensions). This vast range of wavelength (or photon energy) requires a hierarchy of specialized telescopes to collect the light and form the images. All of these techniques must be combined in the pursuit of questions of the structure and behavior of individual astronomical objects. Radio point sources provide a splendid example of objects which were discovered as anomalously bright sources of long wavelength radiation. Half a decade passed before sure identification of these sources could be made with astronomical objects more familiar in visible light.

These objects turned out to be galaxies in peculiar states of evolution or structure, and peculiar nearby stars such as old novae (i.e., the remnants of exploding stars). Generally speaking, space observations complement, but do not replace, ground-based astronomy. In the same sense, no single wavelength domain of ground-based astronomy is in itself sufficient nor could it replace all the other wavelength regions that are used by the inquiring astronomer.

What, then, is the rationale for space astronomy? Figure 217, which shows the transparency of the atmosphere to the radiation spectrum, reminds us that only above the Earth's atmospheric envelope do many important regions of the spectrum become accessible, providing unobstructed and uncontaminated views of radio frequency and infrared spectra, and opening up for the first time the ultraviolet, X-ray, and gamma ray regions of the spectrum. On Figure 218 is a comparison of the Naval Research Laboratory's sounding rocket picture of the Sun's corona and zodiacal light with the best equivalent ground observations ever obtained between total eclipses. The rocket picture reveals very faint corona far from the Sun, whereas the terrestrial telescope is limited to recording only the brightest, close-in coronal regions. This example illustrates how, in the absence of the Earth's scattering atmosphere, it is possible to see objects as much as 10 million times fainter than the Sun, permitting the direct observation of vastly fainter celestial objects. Figure 219 reminds us that the scintillation and turbulence of the Earth's atmosphere limit observations of higher angular resolution to that corresponding to the ultimate performance of a relatively small telescope, about 12 inches in aperture. Thus, by placing larger telescopes above the Earth's atmosphere, it is possible to see smaller structures; that is, to achieve higher angular resolution.

Most of the motivation for observing celestial objects from spacecraft arises, however, from the opportunity to observe them at the extremes of the very long and the very short spectral wavelengths. As figure 217 shows, the peak intensity and the great majority of the Sun's radiant energy falls in the easily accessible mid-range of the spectrum. At the frontiers of research, however, we are concerned with the anomalously strong and fluctuating radiation at the extremes of the spectrum. In these extreme wavelengths we see, almost uncontaminated by simple thermal radiation, those emissions that we generally characterize as arising from non-thermal processes. These processes relate to phenomena such as the generation of radiation by the repeated mirror reflection of particles moving in a magnetic field; or the production of X-rays by pulses of fast electrons moving in rapidly changing magnetic fields. Most of the astronomical phenomena

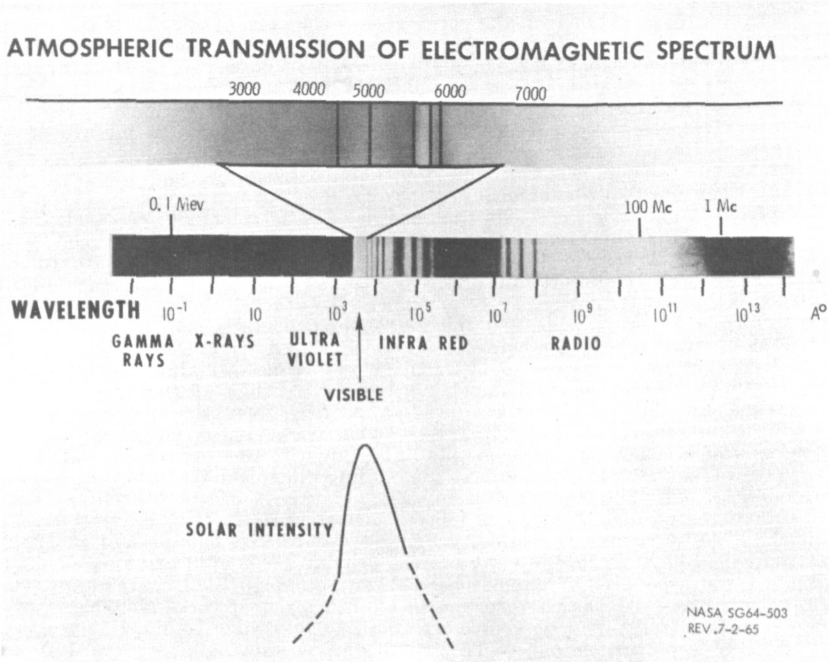


FIGURE 217

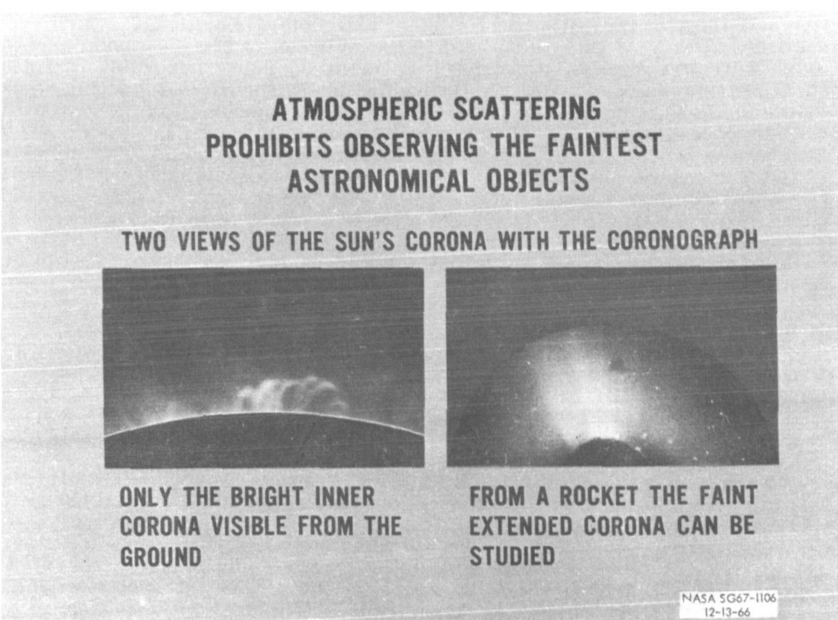


FIGURE 218

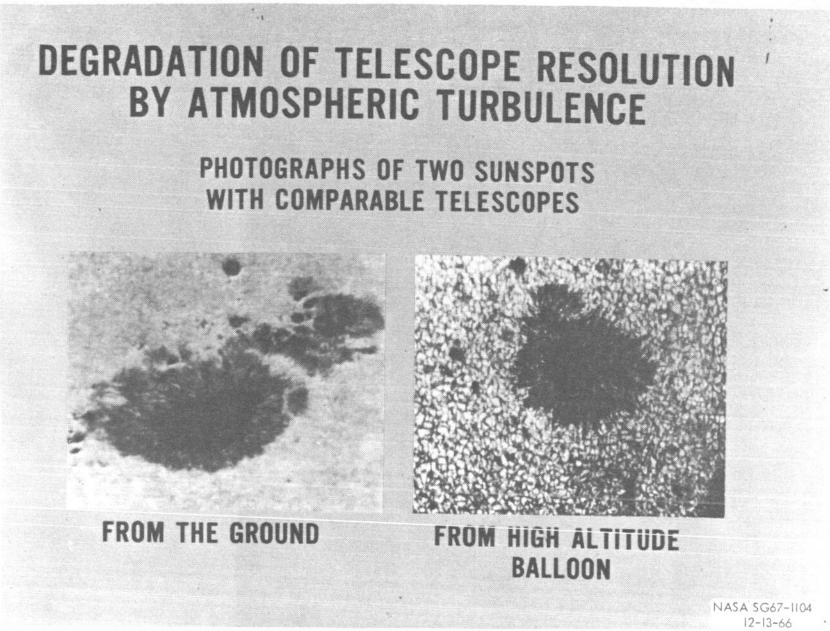


FIGURE 219

observed in visible light can be pretty well accounted for by first order theories, assuming matter nearly in ideal equilibrium conditions. However, non-equilibrium processes discovered in the last two decades, and especially in the last decade of active space astronomy, are believed to be dominant, or at least of equal importance in the universe. The existence of solar X-rays, which was never predicted but only deduced from direct and indirect observations, was a quite surprising discovery and theorists are still hard-pressed to explain their origin. The peculiar processes taking place in the Sun (we call them *non-thermal* processes) are interesting because they reveal otherwise unobservable aspects of celestial objects; for example, gamma rays arising in thermonuclear reactions involving the transmutation of elements. At the other end of the spectrum, radio waves arise from the interaction of very low density streams of extremely hot matter with very weak and extended magnetic fields. The extreme case is the interaction of magnetic fields associated with the structure of the galaxy, the spiral arms, and the highly accelerated charged particles, the galactic cosmic rays. Thus, space astronomy provides us direct observational evidence and vital information on both the smallest and the largest scale phenomena in the universe, together with their interactions with each other and with the stars and matter in the more familiar near-equilibrium states.

Astronomy in the space program bears an essential relationship to other space sciences. In the pre-Sputnik era, remote telescopic observation from the surface of the Earth was the only way to study the Moon, the other planets, the Sun, and the interplanetary plasma. However, space flight has now given us the techniques of direct measurement of these astronomical objects. Astronomy is a worthy and a worthwhile human endeavor, because an essential part of the study of man is his relationship to his environment; and as we know, the Sun controls man's environment.

Figure 220 symbolizes the Sun's dominance of the solar system. Thus, the Sun's temperature and radiative characteristics are significant in determining the conditions of temperature and the state and chemistry of the Earth's envelope and atmosphere. If the Sun were different, the Earth itself would be very different, and very likely an unsuitable abode for life as we know it or life would have evolved differently. Solar protons, which occupy our attention as an im-

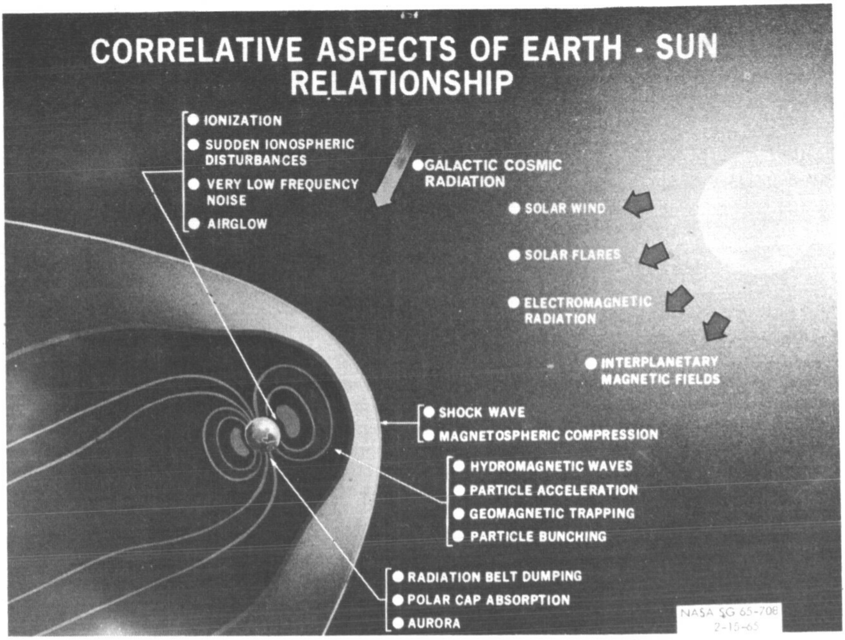


FIGURE 220

mediate problem for astronauts to reckon with in space and on the Moon, in the course of astronomical time must have produced a significant genetic influence on life on the surface of the Earth. One theory of the ice ages relates them to solar activity. The whole history of the Earth's habitability for life as we know it is dependent upon the course and rate of solar evolution. The 11-year solar cycle produces major changes in the near-space environment, not only that of the Earth but that of other planets.

The Sun, however, is a typical star. Thus, we can study the Sun equally well by examining other typical stars, either of different ages, or of similar age but different masses, or different compositions, or different structures. Likewise, we can learn about other stars from the unique close-up which observations of the Sun permit. Figure 221 illustrates two examples of such unique knowledge—the turbulent motions in the Sun's chromosphere, and the beautiful, well-ordered prominences in its corona. Most important of all, the violent activity associated with sunspots, solar flares, and solar magnetism is probably commonplace among the stars.

Figure 222, a sort of catalog of the kinds of objects making up the universe, reminds us of the scope of astronomical research. These range from the nearest (the solar system) to the farthest (the galaxies), from the youngest (the Crab Nebula, not a thousand years old) to the oldest (the Andromeda Nebula, dating from at least 10 billion years ago).

The particular questions of astronomy on which most current research effort is expended, vary according to the nature of the object. Looking at the planets (fig. 223), we seek to learn all we can about the nature of their surfaces, their atmospheres, meteorological processes in their atmospheres, and their natural satellite families. Remember, for the outer planets, telescopes will, for a long time to come, be our only way to study them. For the other bodies of the solar system, also shown in figure 223, telescopic observations will provide the principal knowledge we can hope to obtain of their nature, and hopefully of their relation to the history of the solar system.

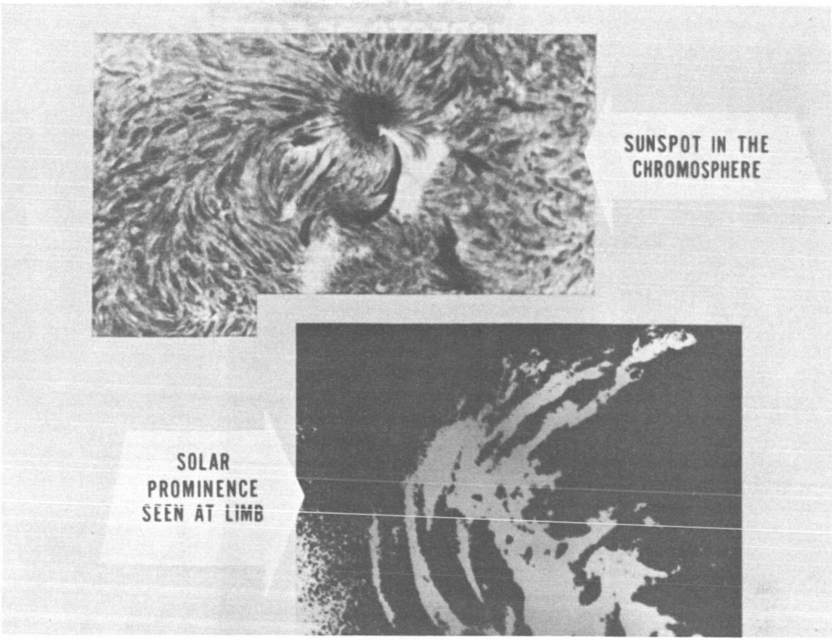


FIGURE 221

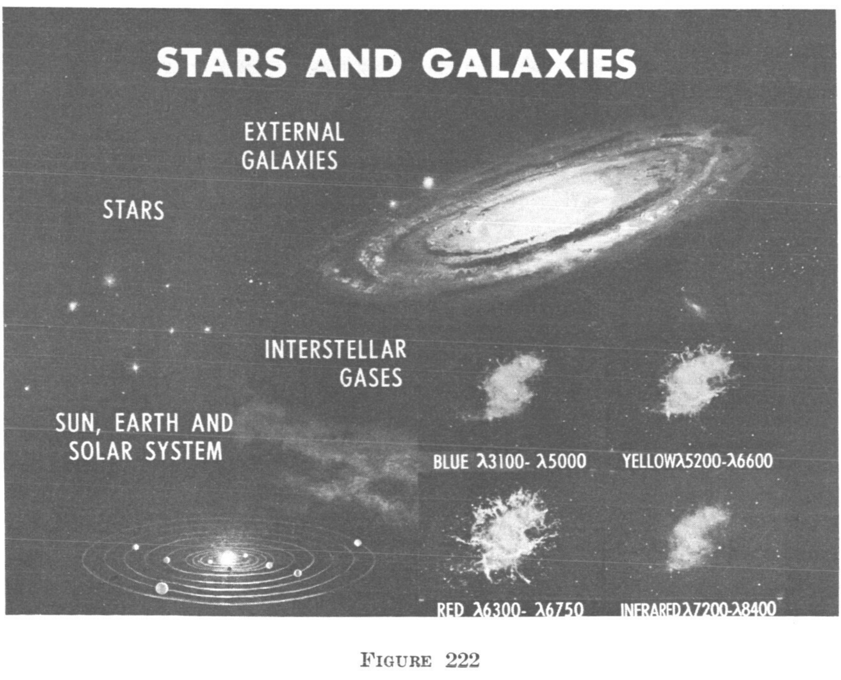


FIGURE 222

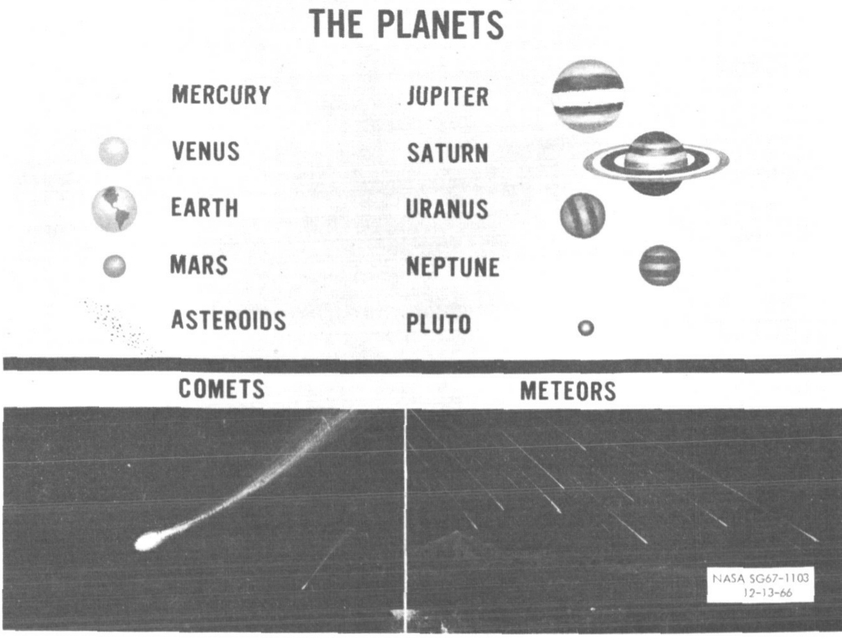


FIGURE 223

For individual *stars*, we want to know the structures of their atmospheres, which we characterize in terms of their temperature and density profiles, their chemical composition, and, if we can, the activity and magnetic fields that occur in them, the counterparts of solar activity. Most important perhaps, we want to learn whether they have planetary systems like the Sun's. At the top of figure 224 is an example of observations from space of the ultraviolet spectrum of a familiar star, Sirius, typifying the space data required for stellar astrophysics. The numerous faint dark lines channeling the spectrum, here photographed in finer detail than ever before, are the tracers of metals and light elements in the denser, hotter regions of the star's envelope. The lower picture is a sounding rocket spectrogram, in the ultraviolet, of the belt stars of Orion. Only in this region of the spectrum is it possible to detect the absorption lines of carbon atoms streaming outwards from these hot, young stars.

By studying many stars to acquire data for what is basically a problem in theoretical astrophysics, we can conjecture on the evolution of a typical star. Such studies immediately raise questions about the evolution of a star out of the primordial interstellar gas and dust. The history of a star is largely one of changing energy generation mechanisms coupled with gradual changes of properties such as the central condensation and total radius of the star. The ultimate demise of a star is something we have never witnessed, but we suspect that it occurs in a series of one or more cataclysmic steps, including the explosive expulsion of its envelope (the Nova process). Stars probably go through cycles of birth and death, receiving material from the interstellar medium, changing their composition of light elements to heavy elements by nuclear fusion, and then returning this altered matter back to the space between stars.

Some stars produce radio bursts and have flares similar in character to solar flares but very much larger in magnitude. The cataclysms of the Nova mentioned above are surpassed in magnitude by the Supernova, whose debris gets scattered far into space. The remnants continue to produce strong radio signals, and in at

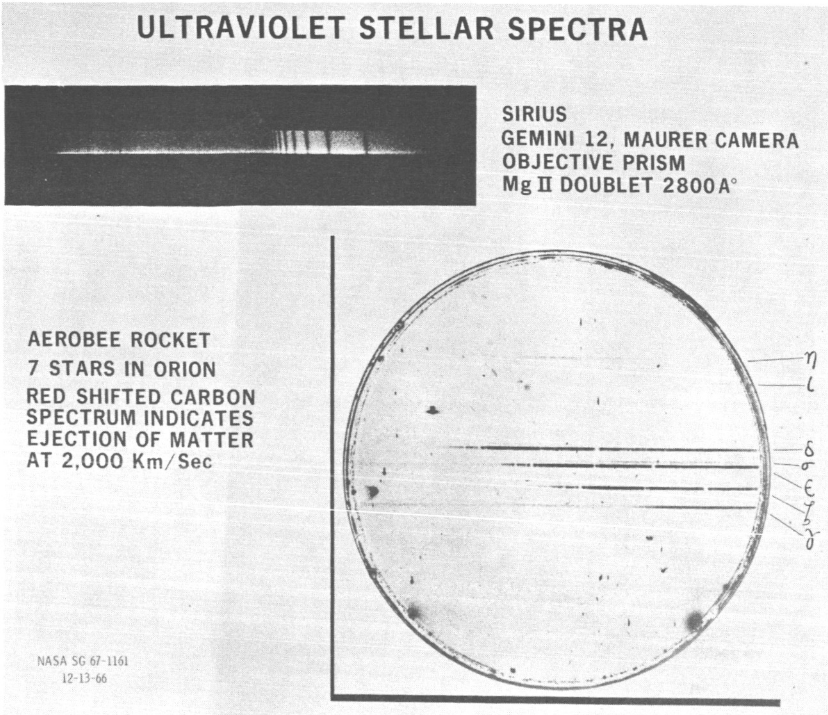


FIGURE 224

least one case, strong X-ray emission observed by satellites and rockets. Figure 225 illustrates one of the most powerful radio stars, which is only faintly recorded by a ground-based telescope in visible light. The point of this chart is just that one of the loudest radio sources in the sky is to the ground astronomer only a faint smudge, which can scarcely be seen on the photograph.

Together with the many fascinating questions about individual stars, there is an array of mysteries relating to the association of stars into star systems. Our Sun has a solar satellite system of planets and comets unique in our experience but probably, we conjecture, a common enough phenomenon. A percentage of the stars are double or multiple, and in the galaxy there are thousands of star clusters. These are families of stars in mutual gravitational association, numbering hundreds, thousands, or tens of thousands. The galaxy itself lies at the other end of the spectrum of galactic stellar systems. It is a spiral, like that shown in figure 222, and is to be contrasted with the numerous elliptical and irregular galaxies which large telescopes have revealed to us.

Much is to be learned by pursuing inquiries into the properties of matter and radiation in interstellar space. The obvious questions concern the composition and state of the medium, and the relation of the gas and dust between stars to stars and star systems. Polarization measurements of star light give us clues to the magnetization of the medium, while the cosmic radiation must be the result of and be controlled by this magnetization. The cold matter between the stars produces radio frequency emission. An important question of the physics of the universe is how energy is distributed between the stars and star systems on the one hand, and the very cold plasma and the dust and gas between the stars on the other hand. The dynamics of clouds of interstellar material interacting with themselves or with stars, and the radiation fields from stars, is an important area of astrophysics. Figure 226, which shows the great Orion

RADIO SOURCE IN CASSIOPEIA,
TAKEN IN RED LIGHT

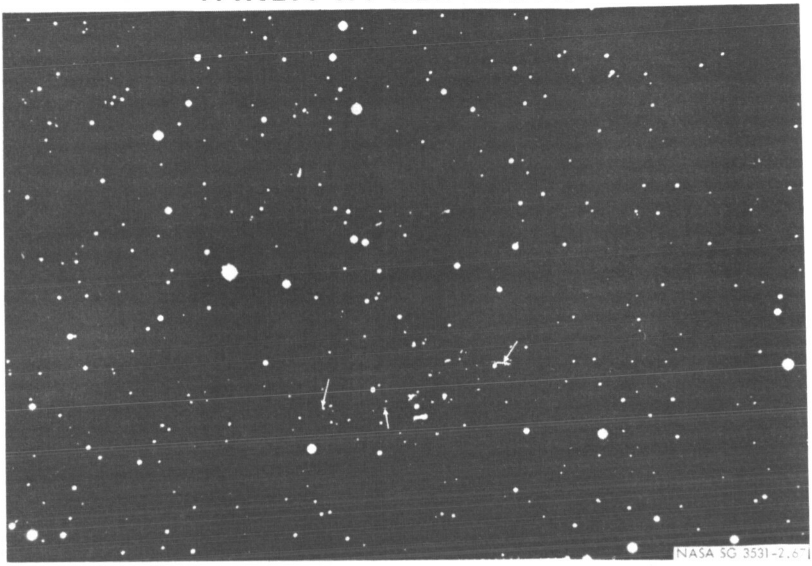


FIGURE 225

FIGURE 226

Nebula, illustrates many of these points—the illumination of the dust by the stars, the emergence of young stars from the plasma, and the hydrodynamic shock waves at critical interfaces.

We already referred to the way chemical elements are changed from one state to another in the interiors of stars, and then returned to the interstellar medium for a second or even a third phase of the history of the universe. The blasts of material from novae are probably one important way that material is returned to the medium. The understanding of the mixing of the old and the new types of stars, called stellar populations, can be cited as one of the triumphs of astronomy in the 1950 decade. Radio astronomers in the last 10 years have discovered, by direct observation of the gas itself, a circulation of the cold plasma through and then back into the Milky Way system.

The physics of the universe, the general discipline of relativistic cosmologies, has been developed largely by studies of the recession of remote galaxies. However, we have succeeded in making direct observations of the residual microwave radiation associated with the initial explosion of the universe. Such data provide the most important, and in many cases the only, information on the most ultimate questions: When did the universe begin? What is its history? and What prospects does it have?

The discovery of those remarkable astronomical bodies, the "quasi-stellar objects," is a good example of how fast this science is developing. At the same time the episode vividly reminds us that exciting new things, of tremendous import for the general goals of astronomy, are still being discovered, and indeed at a faster rate today than ever before.

In their quest to identify radio stars with familiar objects in the visible spectral region, astronomers were baffled by a class of strong radio sources which did not appear to be either peculiar galaxies or supernova remnants. About three years ago, however, it was discovered that a number of these radio noise centers could be identified as very peculiar blue star-like objects. Their spectra showed exceedingly large red shifts, corresponding to motions away from us at speeds of the order of one-fifth to one-third the velocity of light. Since the initial discovery of these quasi-steller radio sources, astronomers have compiled a list of about 65 for which velocity measurements have been made. It was immediately recognized that many faint blue objects in the sky may be similar high-velocity interlopers, but not radio sources. The ratio between radio-quiet and radio-emissive objects may be as high as 100 to 1.

Almost certainly the large red shifts means that the objects are receding from us very fast. If we apply Hubble's Law (the fundamental law of the expanding universe, which relates distance to recessional velocity), one can conclude that these objects are very remote, and correspondingly very bright. In fact, they would be some 40 times brighter than the largest galaxy known. A stupendous energy budget would be necessary to keep such objects shining continuously for any extended period of time. An alternative theory would place the quasi-stellar objects closer to us, and about 10,000 times smaller, still so large and so bright they stagger the imagination. To compound the problem, several of these objects vary irregularly in their brightness, over times of the order of a few weeks. This datum sets an upper limit on the size of quasars, since they cannot be so large that a light ray takes more than about a month to traverse from one side to another. Thus, we discovered the brightest and most remote objects in the universe only three years ago. They present ponderous difficulties in interpretation, and it is fair to say we have not begun to understand what they are or how they operate.

Let us look at some of the highlights of space astronomy. The two examples chosen concern observations of X-rays, first from the Sun, second from cosmic sources. We mentioned earlier that the simple near-equilibrium theories of celestial bodies do not predict any notable X-ray emission. However, even 25 years ago, fadeouts of radio signals correlated with solar flares, indicating some ionizing radiation was emitted by the Sun during those energetic events. Theories predicted that either ultraviolet or X-rays would be the cause. It was only in the post-war era that sounding rockets in the hands of Naval Research Laboratory (NRL) scientists demonstrated conclusively that it was X-rays that caused this shortwave fadeout. As our space technology improved, the Orbiting Solar Observatory provided high resolution spectra of solar X-rays, and enabled us to measure the low rate of X-ray emission during quiet solar conditions as well as during the occurrence of events like flares, when the Sun's X-ray brightness rose by orders of magnitude.

At the present time we are able to make direct photographs of the Sun with X-ray telescopes, such as illustrated in figure 227. This very low resolution rocket X-ray solar photograph is a foretaste of the fascinating new kinds of information we expect to receive about solar activity when the Apollo Telescope Mount X-ray telescopes are put into operation a few years hence.

Discovery of the emission of X-rays by cosmic sources is another one of the great accomplishments of space astronomy. The discovery of cosmic X-rays occurred during a sounding rocket flight conducted in 1962. The first flight indicated sources in the constellations Scorpio, Cygnus, and Taurus. These were soon confirmed by other scientists working independently. NRL scientists took advantage of an exceedingly rare event, the occultation (i.e., the eclipse) of the Taurus source (seen in fig. 228, as photographed with the 200-inch telescope) by the Moon, to show that the X-ray emission was not from a point source, and accordingly could not be from a neutron star (a superhot, superdense type of star postulated to explain cosmic X-ray emission). Numerous sounding rockets have flown since the first discovery four years ago, to provide fairly detailed information on the list of more than 20 known sources as shown in figure 229. We know now that these sources lie near the Milky Way, and so are probably not nearby objects. At least two types of sources exist, including radio galaxies (like the Cygnus radio source, and the peculiar external galaxy, M87) ; a second type are old novae, like the Taurus (Crab Nebula), and the Scorpio source. The very precise identification of the Scorpio X-ray source was made possible by high resolution position determinations with a sounding rocket. This determina-

FIGURE 227

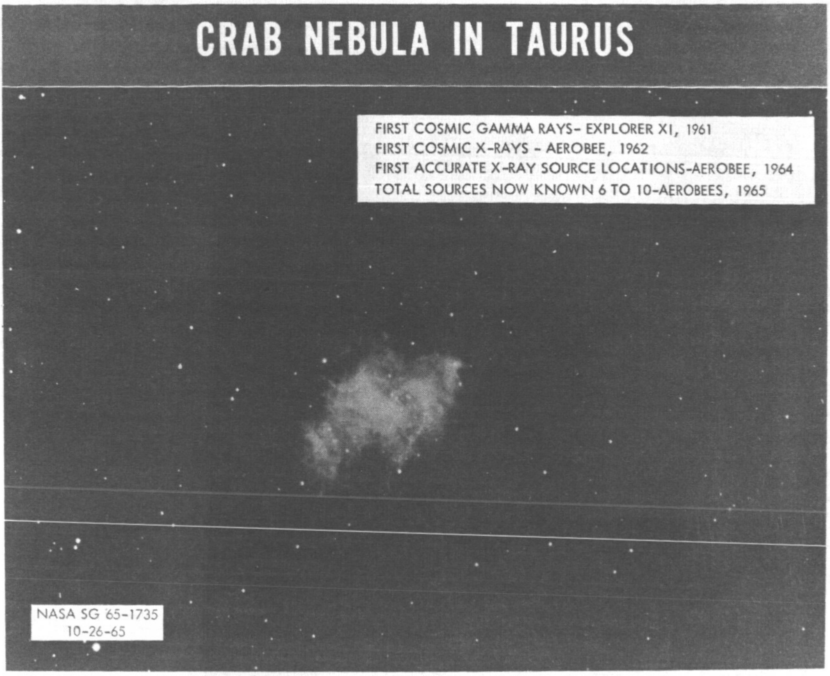


FIGURE 228

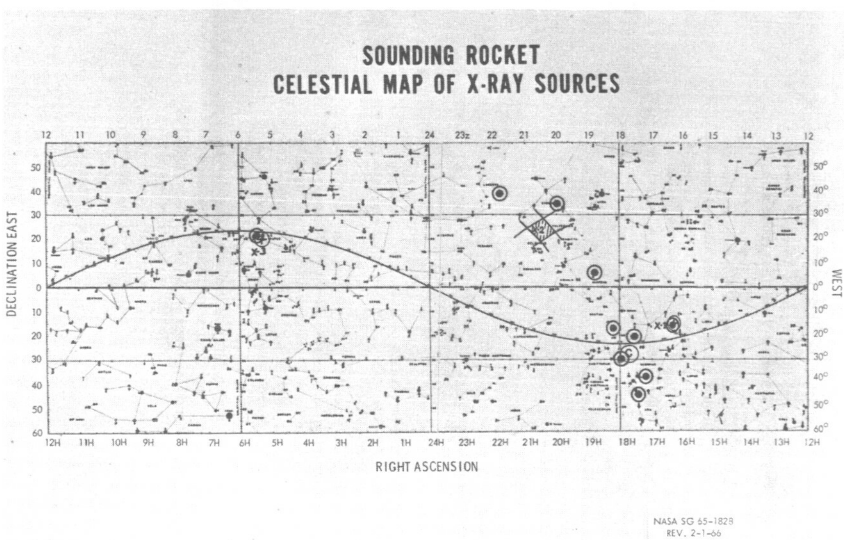


FIGURE 229

tion permitted an optical search for peculiar objects in the vicinity with ground-based visible light telescopes, and the very firm identification of the object. It was a very faint star, which raises the question: Why is it 1,000 times brighter in X-rays than in visible light? We know of many such old novae, but the extreme difference between the X-ray and visible brightnesses of this object is unique.

Discoveries of cosmic X-rays have provoked numerous theories to account for their origin; namely, involving the interaction of fast electrons with electric or magnetic fields. No single mechanism seems to account for all the observations. These questions are all at the frontiers of research and any answers we might indicate are very likely to be overthrown by observations in the near future.

Let us take a concluding look at space astronomy of the future. Because astronomers are primarily dealing with faint objects and want more and more high resolution observations, it is important that we attain large aperture telescopes, simply for brute force collection of more light from faint stars. The more refined theories we can apply require more refined energy resolution; that is, higher wavelength discrimination. This implies larger spectrographs, which in turn require smaller images, hence, higher telescope resolution and greater pointing accuracy. The large apertures associated with large collecting areas will simultaneously permit us to see smaller objects, down to the limit of the wavelength of light.

The history of progress in astronomy has always been marked by mileposts of improved techniques of observation. Each major advancement in the power of astronomers' tools has resulted in new discoveries, then has revolutionized our understanding of nature.

Figure 230 demonstrates, using the Andromeda Nebula as an example, what a series of radio telescopes would see at the indicated resolving power limits. One can identify a bright object at one-half degree; its spiral structure and differentiation become visible at one arc minute; and with one arc second, one

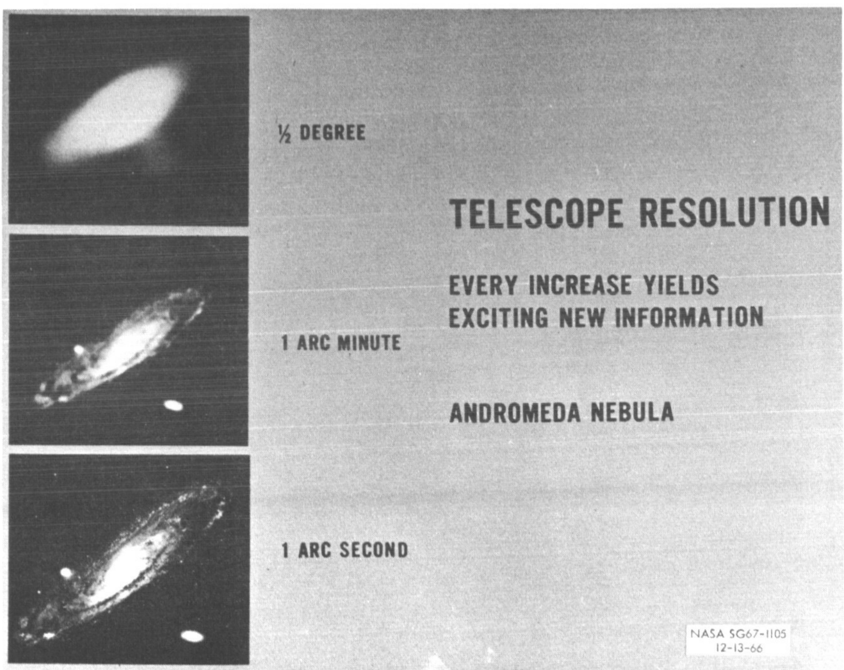


FIGURE 230

can study individual stars, star clusters, gas and dust clouds of the system. Exactly the same hierarchy of understanding would be true in X-ray astronomy, or as applied to the Sun or planets, and in visible light. Harlow Shapley, who taught so many American astronomers, recently recalled how, 50 years ago, he and his colleagues on Mt. Wilson thought Galileo's one-inch and Hale's sixty-inch telescope were the two most important telescopes. The former discovered Jupiter's moons, Venus' phases, and resolved the Milky Way into stars. The 60-inch, taking advantage of the power of photography to accumulate light from faint objects, revealed the true size and nature of the Milky Way system as a spiral galaxy, the nature of galaxies as "island universes," and indeed the true size of the universe. Today we would add the 200-inch telescope to this list, coupled with large radio telescopes. In the past two decades these great instruments have revealed exploding galaxies, the nature of radio stars, including the quasi-stellar radio sources, and have given valuable insight into the history of the universe.

Already space astronomy has revealed that this current extension of telescope power into previously forbidden spectral regions will again bring new knowledge and raise further questions.

To create and utilize large telescopes of the magnitude considered (up to 10 feet in diameter) an astronaut almost surely will be necessary to achieve desired flexibility and reliability. For the present, of course, we shall pursue vigorously the Orbiting Astronomical Observatory technique of fully automated remote control telescopes of intermediate aperture. The next generation of space telescope, which we call Manned Orbital Telescope (MOT) (fig. 231), always conjures up first a very large aperture visible, ultraviolet, and infrared light reflector. But in addition, a space observatory will include radio telescopes, a variety of specialized telescopes for solar observations, and for cosmic X-ray and gamma ray studies.

The motivation for a vigorous program in astronomy is clear: the objectives of basic knowledge which have inspired astronomical inquiry from earliest times

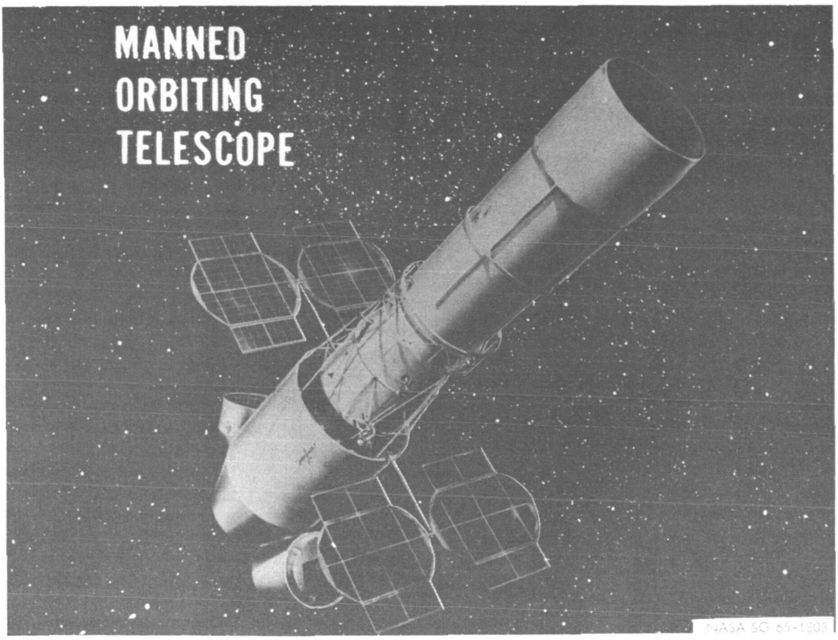


FIGURE 231

continue to be valid reasons for studying the objects of space. The basic question before us is at what level of effort and at what pace should the astronomy program pursue these objectives.

We believe astronomical research will prove to be a worthwhile and appealing way to utilize Saturn/Apollo hardware, and beyond that as part of the use of a future space station.

Appendix VIII. Space Research and Progress in Biological Science

Orr E. Reynolds, Director, Bioscience Programs, Office of Space Science and Applications, National Aeronautics and Space Administration

Virtually everywhere on Earth we look for life, we find it . . . from the tropical rain forests (fig. 232) to the barrens and ice caps of the polar areas (fig. 233) and from mountain slopes (fig. 234) to the abyssal depths of the oceans (fig. 235). In even more severe areas of mountain peaks (fig. 236) and the dryest deserts (fig. 237 and fig. 238), we find a wide variety of organisms but they are simple forms, mostly micro-organisms (fig. 239). Figure 240 shows a Tardigrade, or moss animal, a rather highly advanced animal in the phylogenetic scale which can be dehydrated, shriveled up to almost crystalline appearance, and when provided with water can begin to crawl around again, and to reproduce itself.

Recently a natural "experiment" occurred which demonstrates one of the general traits of living organisms, that is that they will invade and rapidly populate any environment accessible to them. Figure 241 is a photograph of the volcanic island, Surtsey, which has been in the process of forming off the coast of Iceland for the past two or three years. This island has already been successively populated by organisms, the population being killed off every few months by an eruption, but new organisms establishing themselves each time—either drifting there in the ocean currents or carried there by birds.

FIGURE 232

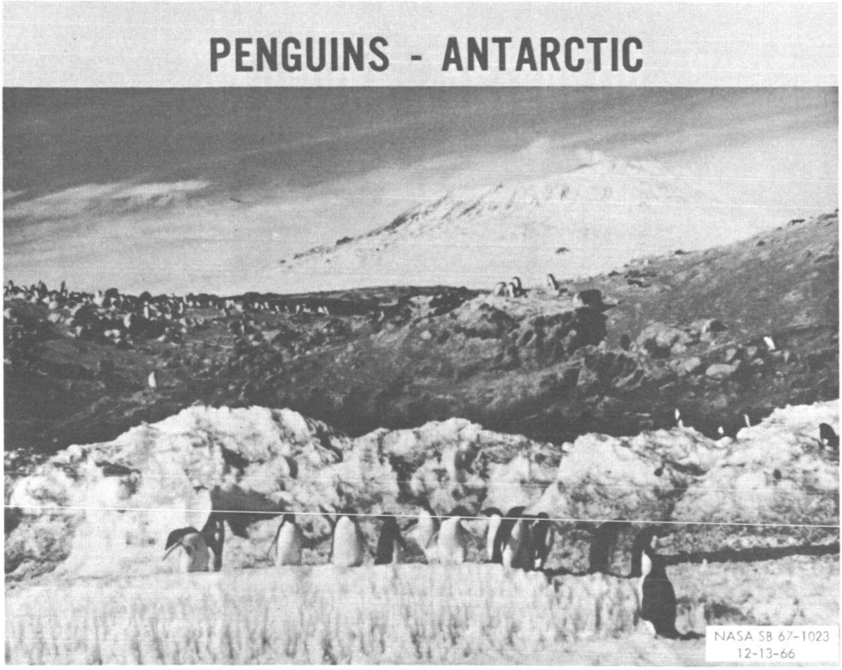


FIGURE 233

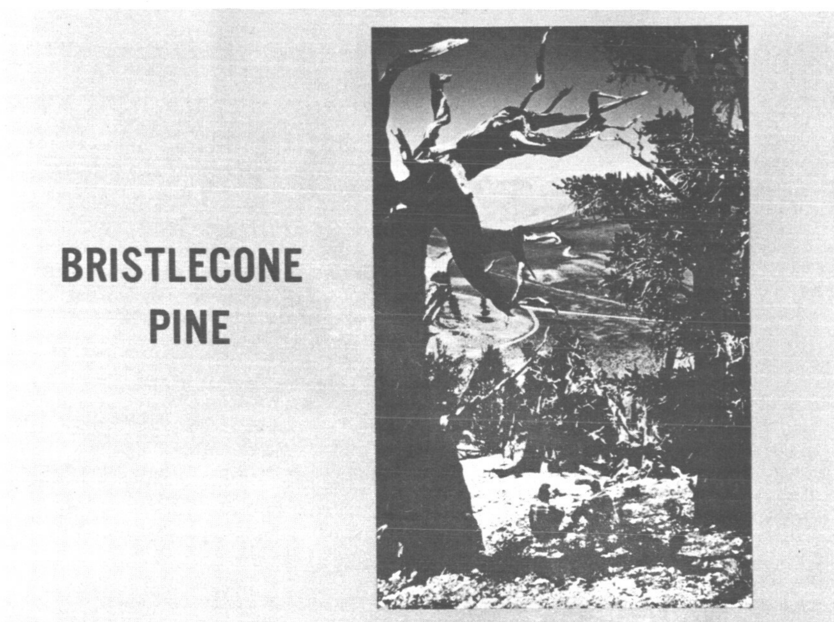


FIGURE 234

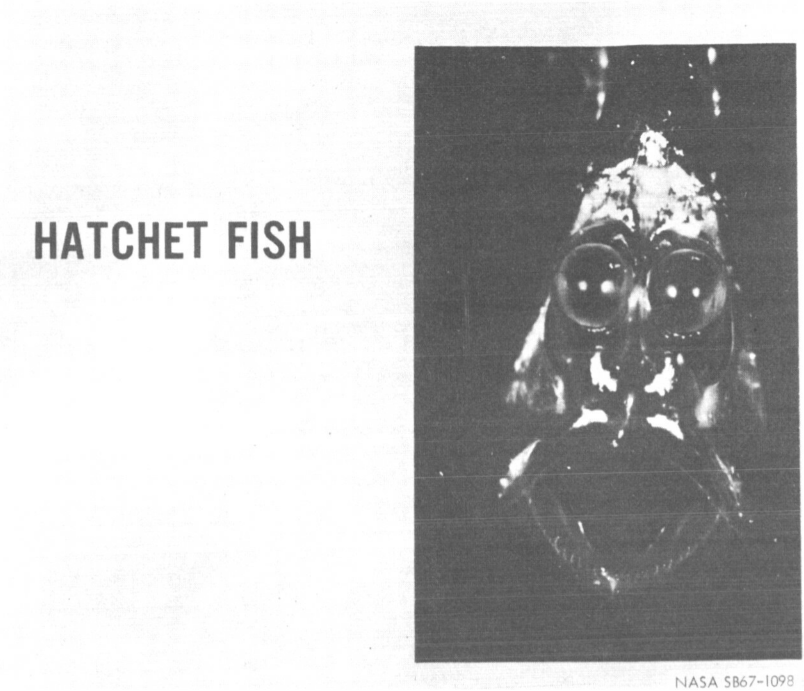


FIGURE 235

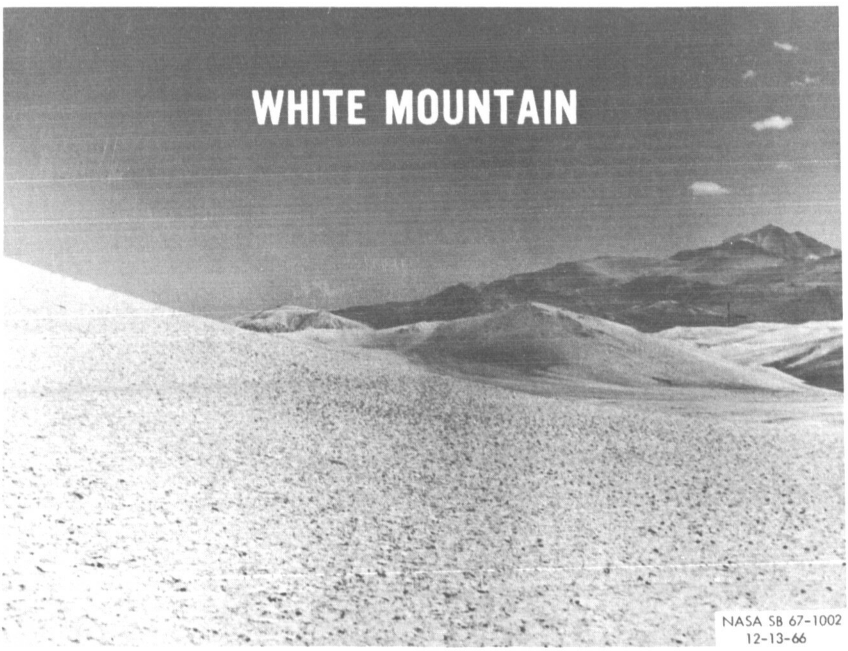


FIGURE 236

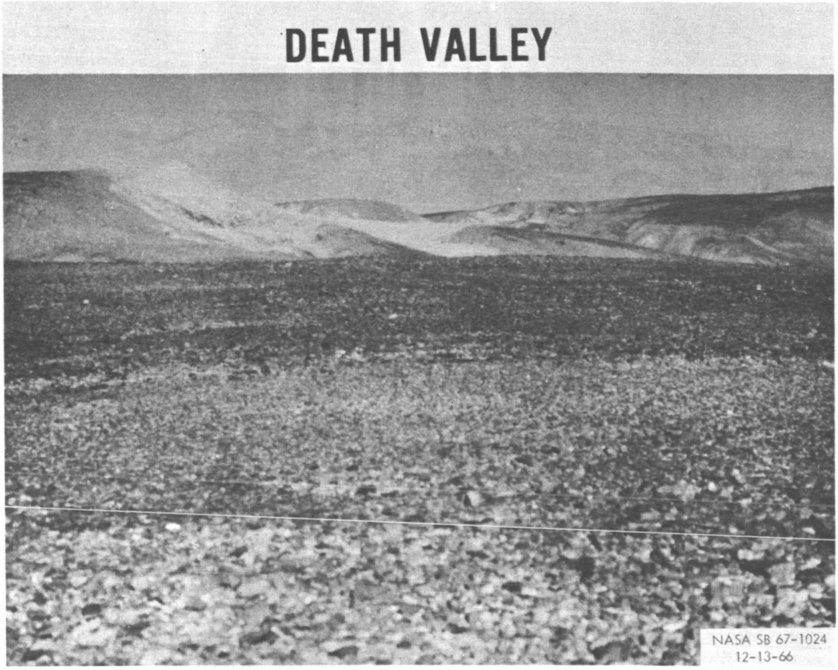


FIGURE 237

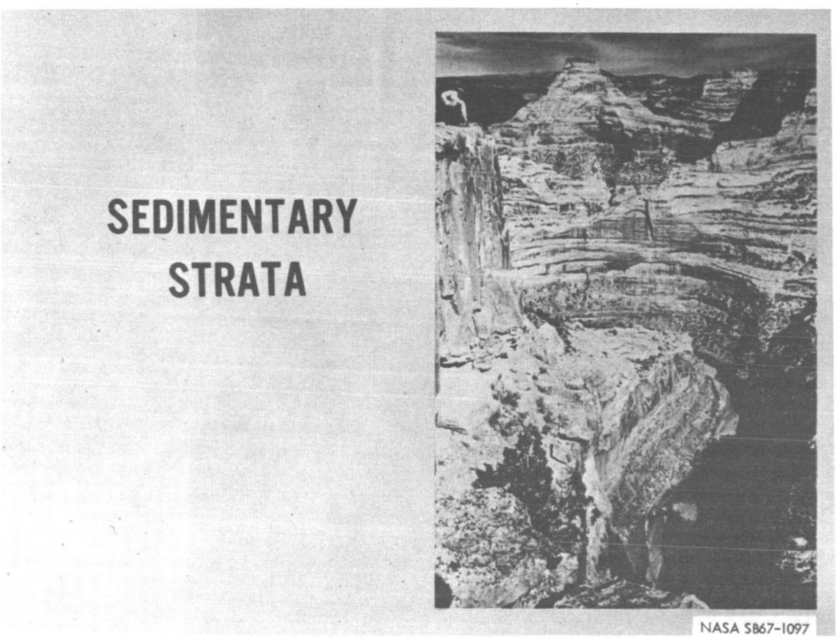


FIGURE 238

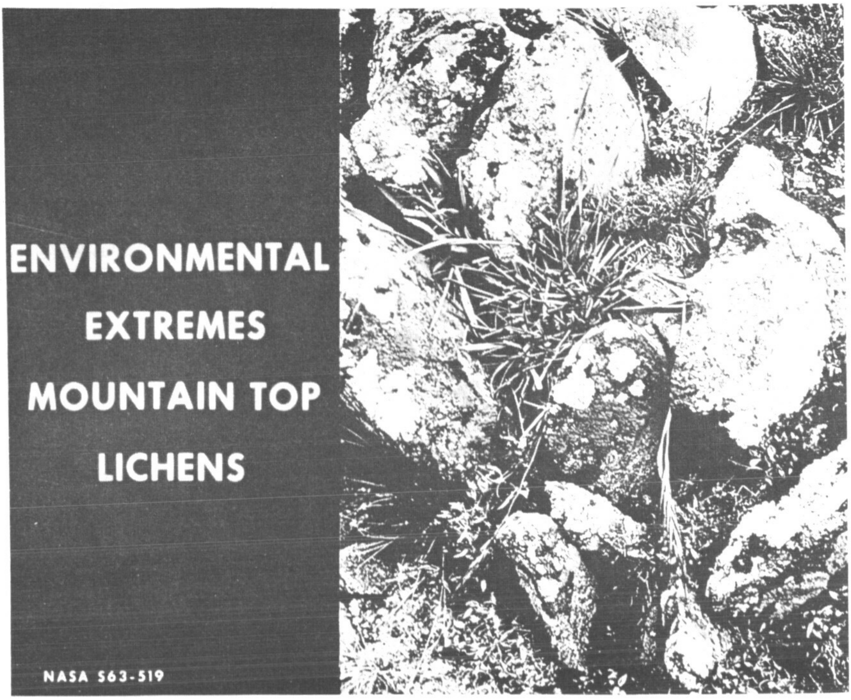


FIGURE 239

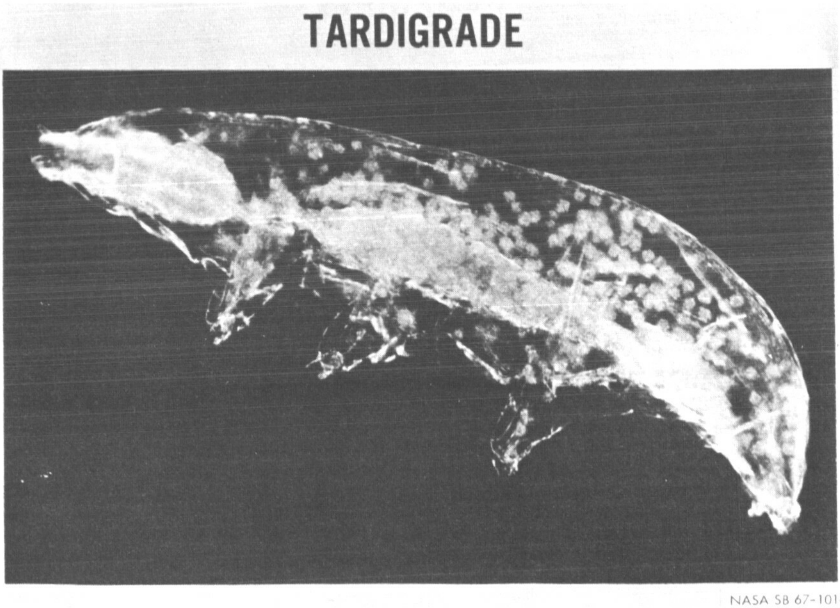


FIGURE 240

FIGURE 241

Looking at life on a dimension of time rather than of geography, we find a spectacular series of organisms have populated the Earth, some of them extinct (fig. 242), and some (fig. 243) of quite recent origin. Some of the existing forms, however, have been in existence on the Earth for a long time. The Limulus (fig. 244) or horseshoe crab is familiar to many of us along the Atlantic Coast. As you can see, he is a very close relative to the Trilobite, which was the dominant animal on the Earth about 500 million years ago, remaining dominant for about 100 million years. Figure 245 shows the serpent starfish, a modern living organism, and you can see that it is practically identical with the 400 million year old fossil shown in the same figure. The serpent starfish is the predominant macroorganism in the very deep trenches of the ocean bottom today. We can find evidence of life even further back in the history of our planet. There is a sedimentary deposit in the Sudan, Africa, called the Fig Tree Chert. ("Chert" identifies the type of rock, and "fig tree" the shape of the formation.) Figure 246 is a section of the cliff face in which the collection was made, and from which a piece of the rock was removed (fig. 247). This material is computed to be 3.1 billion years old. Barghoorn, one of our grantees at Harvard, isolated the fossil bacteria (fig. 248) from the rock. It appears that these organisms were living there 3.1 billion years ago, more than three-fifths of the age of the Earth.

An even more interesting fossil, also discovered by Barghoorn, appears in figure 249 and is only 2.7 billion years old. When Dr. Barghoorn published this picture, another scientist, Sanford Siegel, working on a NASA contract at Union Carbide, thought he recognized it. He went back through the cultures that he had been running to determine the type of strange environments in which Earth organisms live and found an example of what is apparently the same creature, shown on the right of figure 249. This organism is interesting because it was cultured from the soil around the wall of Harlech Castle in Wales, and will grow only in an atmosphere containing about 30–50% ammonia. The high content of ammonia in the soil around Harlech Castle walls is occasioned by the fact that for hundreds of years the castle garrisoned troops which used the Castle wall as

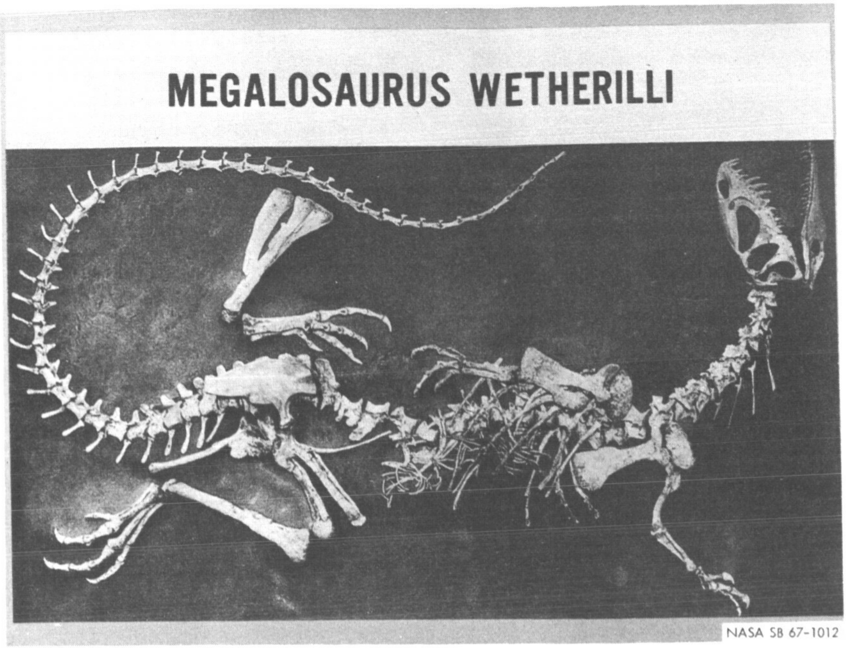


FIGURE 242

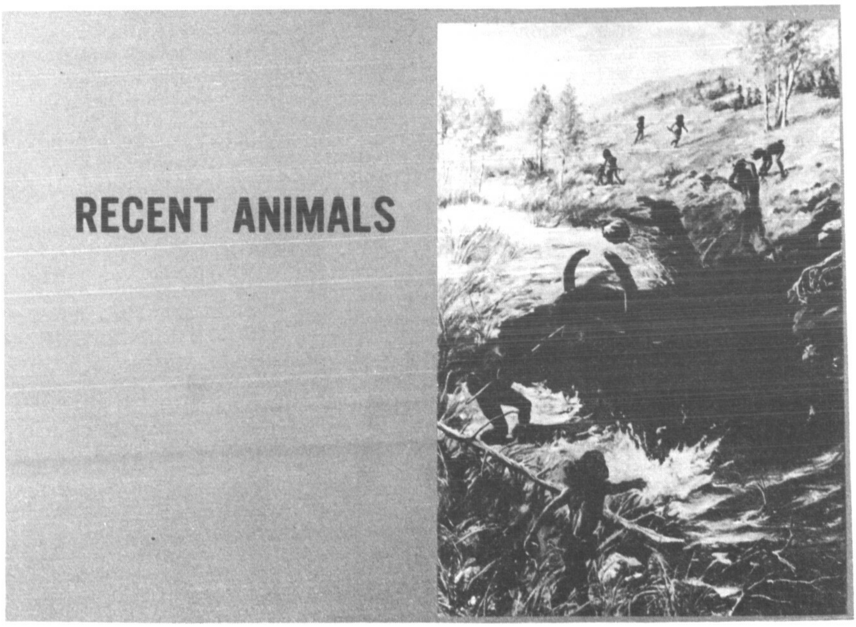


FIGURE 243

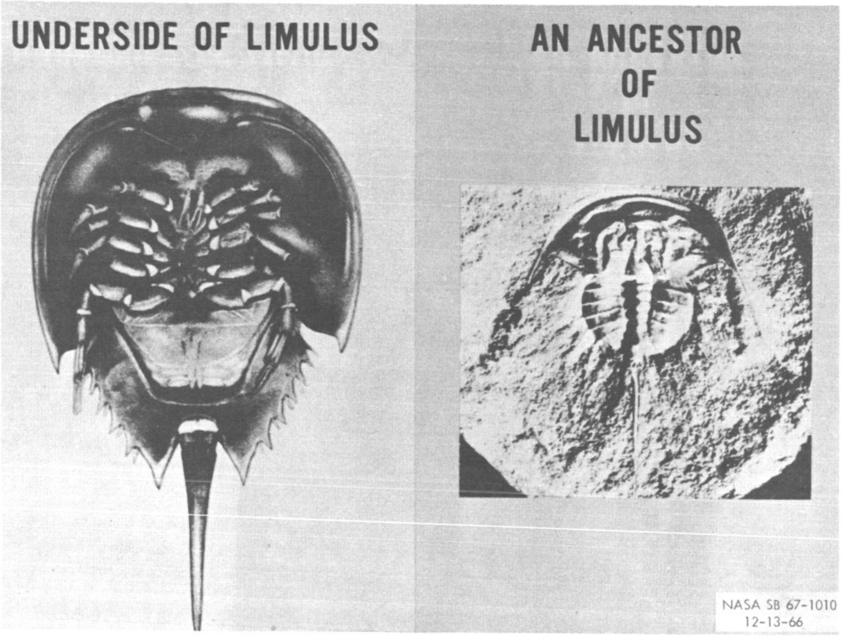


FIGURE 244

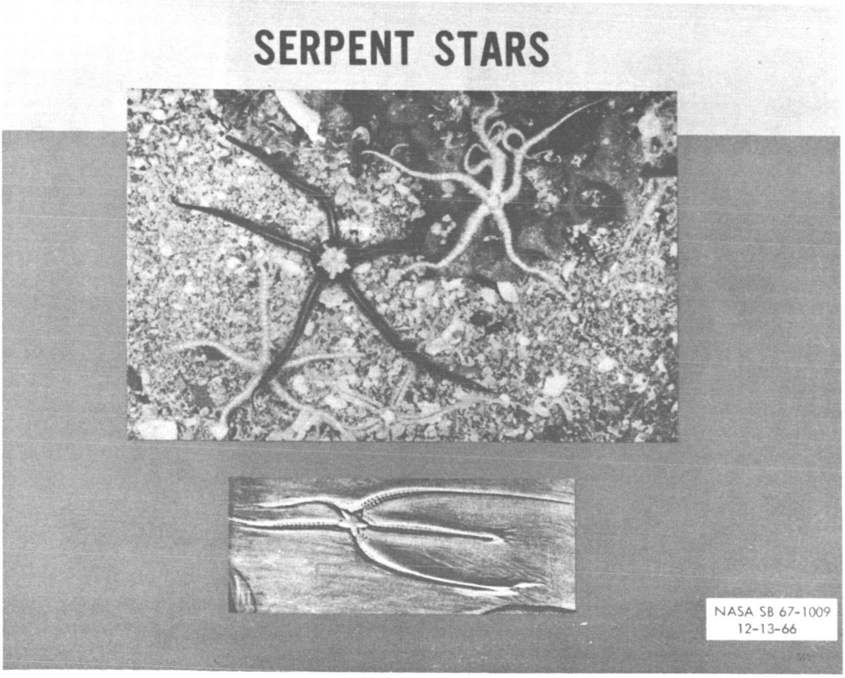


FIGURE 245

FIGURE 246

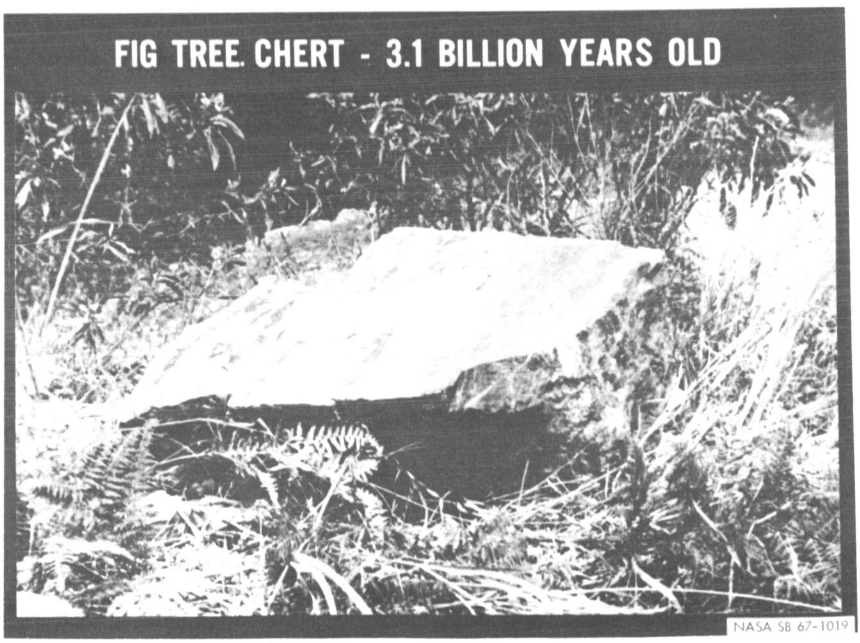


FIGURE 247

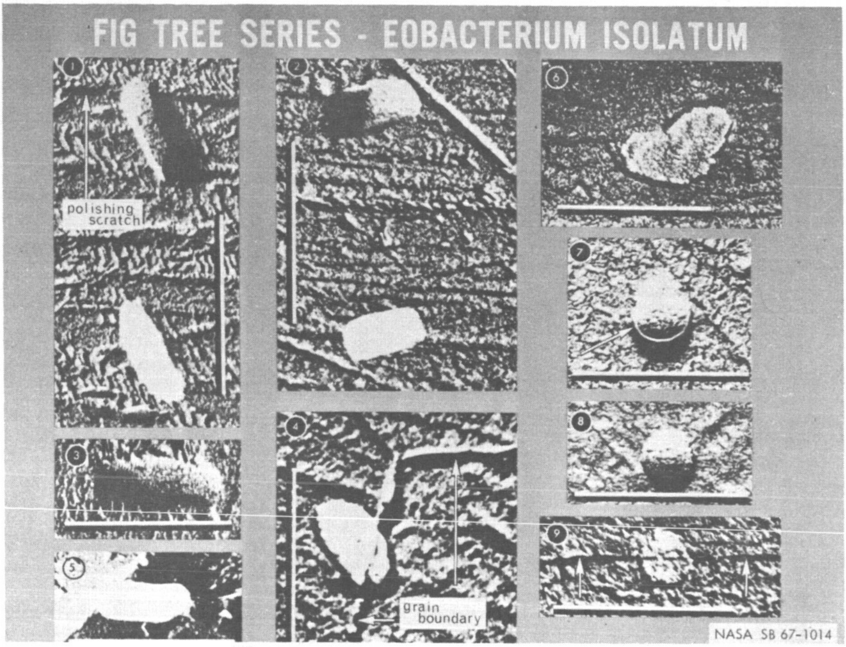


FIGURE 248

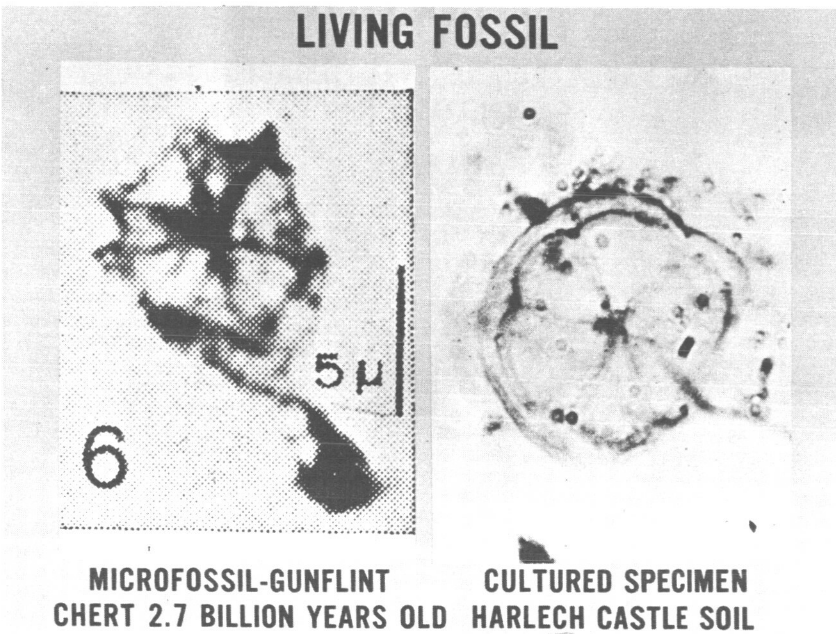


FIGURE 249

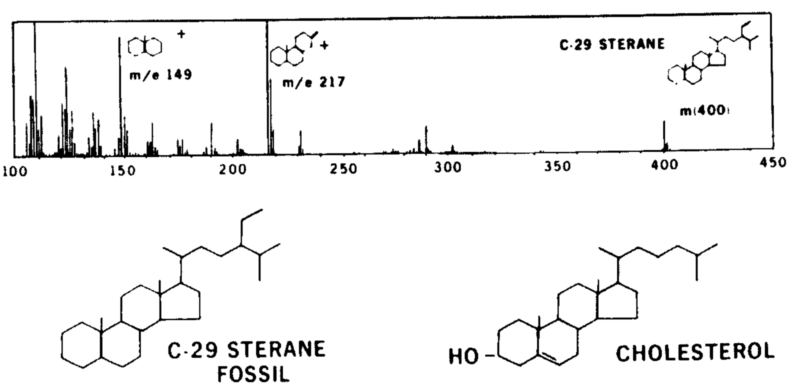
a urinal. In recent years it has been similarly well supplied by the children of the tourists. This is interesting because ammonia is thought to have been one of the components of the primitive atmosphere of the Earth. It is interesting to speculate that these microbes developed when the Earth was in a quite primitive state.

There are evidences of life more fundamental than bone skeletons, such as chemical "skeletons" of organic molecules. It happens that the type of molecule shown in figure 250 we know only in rather advanced living forms. This rather complex carbon chain, called a "*sterane*" is found in various forms in living things substituted with various functional groups. Once such derivative is a "steroid" such as keto steroids used in our attempts to cure arthritis; another is a "sterol" (cholesterol) with which we are all familiar and which we hear about if only at the time of our annual physical.

It appears from the foregoing, that even in this very ancient time, at about 3/5 of the age of the Earth, complex living forms were present. The significance of that fact to our concern with the origin of life here and elsewhere is the point that, if life did originate so very early in the history of this planet, its origin must have been a more probable event than if it had occurred later. If life is unique to this planet and does not exist anywhere else in our universe, then the probability of its occurrence is something like one in one hundred billion billion (the number of "solar systems" in the visible universe), an almost unthinkably low probability. If, on the other hand, life is encountered on some other planet in our solar system, it would appear to be a very probable event, and must have occurred many, many times in the history of our universe. As Pittendrigh has said, it is this question which makes the search for life outside the Earth so fascinating. It amounts to no less than the fundamental question of "man's place in nature."

Now we come immediately to the present status of "theoretical biology" (fig. 251). The theory of organic evolution was developed primarily by Darwin and his colleagues, about the middle of the 19th century after they had seen an array of such creatures as you saw in the first few figures of this text. Evolution as described by Darwin is simply the method by which life is able to adapt to en-

MASS SPECTRUM OF THE STERANE "FOSSIL" FROM THE COLORADO SHALE



SIMILARITY IN CHEMICAL STRUCTURE BETWEEN THE C-29 STERANE FOSSIL MARKER AND CHOLESTEROL.

FIGURE 250

THEORIES IN BIOLOGY

- THEORY OF EVOLUTION—LONG TERM ADAPTATION TO ENVIRONMENT
- THEORY OF GENETICS——MECHANISM OF GENERATING AND PRESERVING USEFUL CHARACTERISTICS
- PRINCIPLE OF HOMEOSTASIS——SHORT TERM ADAPTATION TO ENVIRONMENT

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FIGURE 251

vironment over the long term. The *principle of homeostasis* is a physiological principle, the formulation of which was developed about the same time. It is the basis on which your breathing rate increases if you go to a high altitude, and the pupil of your eye contracts when you are faced with a strong light—it is the short-term adaptation that animals and plants demonstrate. Both of these types of adaptation are made possible by the genetic mechanisms, which I think of as the mechanism by which living things generate and preserve useful characteristics.

The main accomplishment which has been made in biology since the middle of the 19th century is the attainment of knowledge of how such a mechanism operates at the molecular level. The picture in figure 252 (recently in Life Magazine) is of a very complex structure, deoxyribonucleic acid (DNA) the code carrier by which genetic characteristics are preserved after they are generated by random "accidents" in the formation and location of atoms in this molecule. Now when I say "random accidents," remember that the number of accidents must be extremely small or there would not be the persistent stability in living things that does exist. The reason for such stability is the fact that the architectural precision of these molecules is very high, requiring a precise chemical configuration and arrangement of atoms. Figure 253 illustrates one clue that we have as to the way this precision is generated.

A young chemist named Louis Pasteur in the 1800's received his Ph.D. degree for work done on the substance *sodium ammonium tartrate.* He discovered that this substance has the property of forming two different types of crystals which are mirror images of each other, as shown in figure 254. This property shows up better in stereoptical photography, but one can see that the crystal in the upper left is an exact mirror image of the crystal in the lower right, and so on. That this property of the crystals is a property of their constituent molecules is shown by the fact that the molecules, when in solution, have the property of rotating polarized light to either the right or left direction depending on which configuration was used. Living things somehow have the property of selecting and manufacturing only one of these optical isomers in each case. We humans, for example, use the sugar glucose, that rotates light to the right, and the amino acids that rotate it to the left. This phenomenon is the basis for at least a part of the precise architecture of our chemistry.

The chemical composition of living things itself is very interesting. Figure 255 is a chart of cosmic abundance.

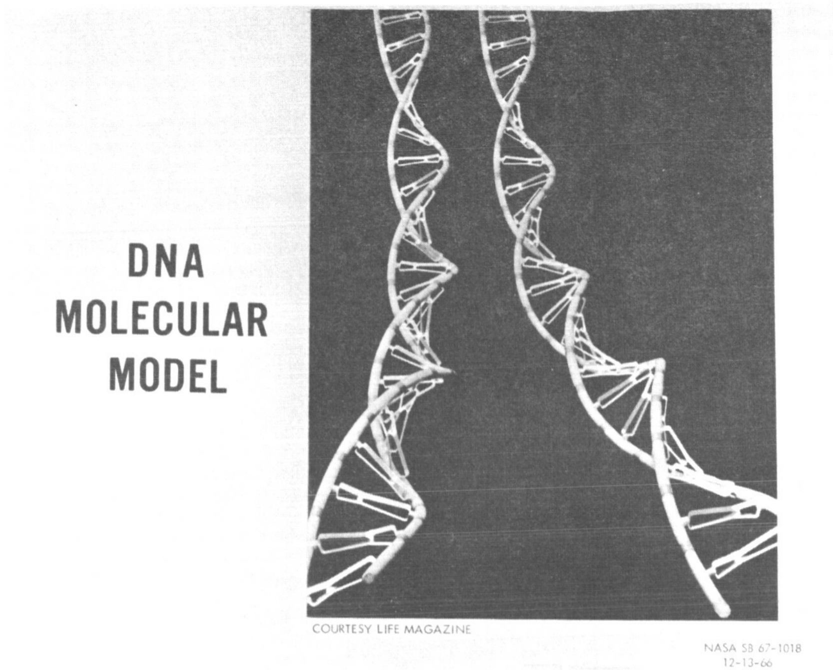

FIGURE 252

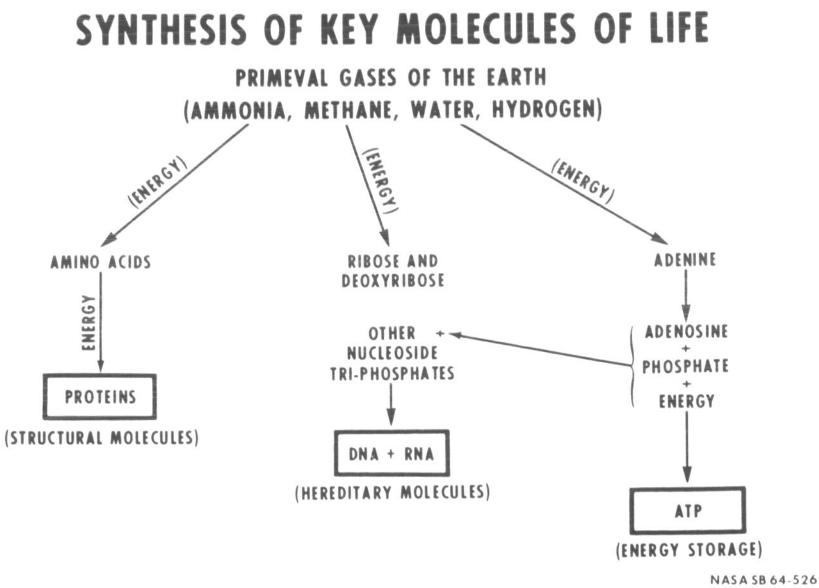

FIGURE 253

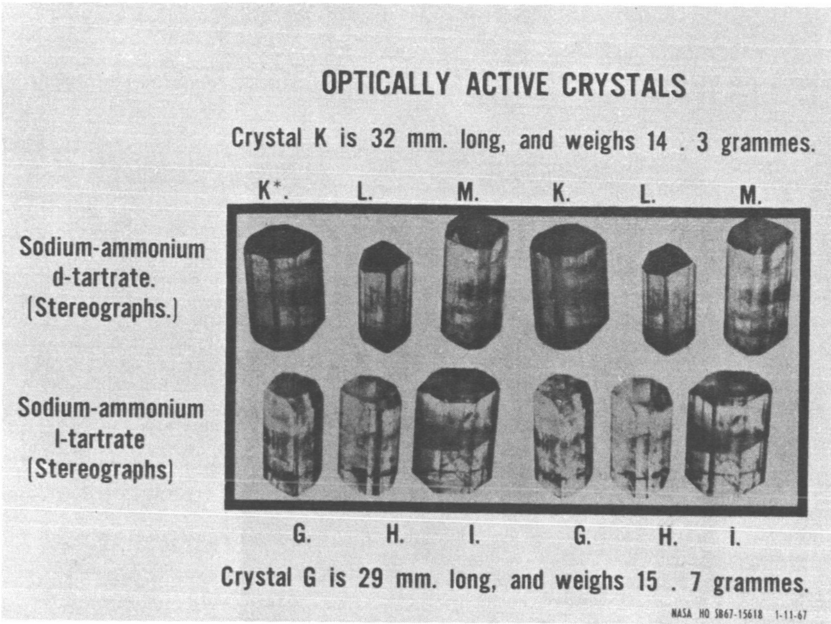

FIGURE 254

RELATIVE ABUNDANCE OF ELEMENTS

ELEMENT	COSMOS	EARTH: ATMOSPHERE HYDROSPHERE	EARTH: CRUST	LIFE: PLANT (%)	LIFE: ANIMAL (%)
HYDROGEN	1,000.0	2.0	0.03	10.0	10.0
HELIUM	140.0				
OXYGEN	0.680	9.978	0.623	79.0	65.0
CARBON	0.300	0.0001	0.0005	3.0	18.0
NEON	0.280				
NITROGEN	0.091	0.003		0.28	3.0
MAGNESIUM	0.029		0.018	0.03	0.05
SILICON	0.017		0.211	0.12	
IRON	0.008		0.019	0.02	0.004
ARGON	0.004				
SULFUR	0.003	0.0005		0.01	0.25
ALUMINUM	0.0019		0.064		
CALCIUM	0.0017		0.019	0.12	2.0
SODIUM	0.0017	0.0008	0.026	0.03	0.15
NICKEL	0.0005				
PHOSPHOROUS	0.0003			0.05	1.0
POTASSIUM	0.00008			0.32	0.35
OTHERS	0.00015	0.011	0.020	0.04	0.156

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FIGURE 255

Of the six most abundant elements, four are the primary constituents of living organism, hydrogen, oxygen, carbon and nitrogen. Helium and neon are not involved in living forms but they are the so-called "Noble gases" that do not participate in normal chemical reactions, so they are more or less eliminated. These same four elements that make up living material were predominant in the primitive atmosphere of the Earth.

The laboratory apparatus shown in figure 256 has helped to demonstrate that most of the fundamental building blocks shown in figure 253, and which form the large molecules on which our metabolism genetics and energy exchange are based are generated under abiogenic conditions. Unfortunately, under the abiogenic conditions both mirror images of each molecule are synthesized so that this material cannot give rise to life. The precision required in the structure of the molecule does not allow for such "randomness" of its constituent components. The process itself of evolution from a drop of the "warm dilute soup" of random mirror image molecules, referred to by J. B. S. Haldane, to the extremely precise structure that is required for living processes, is probably the most fundamental and fascinating question in biology. It most certainly is one of our *primary* reasons for wanting to search for extraterrestrial life. So far as we know, from only one kind of life (that on the Earth), it appears that the same kind of chemistry is represented in a range, from the most primitive forms on Earth to the most advanced. It would appear that all forms of life on Earth are related, or in other words, that there was one origin of life on Earth from which all living forms descended. The only real answer to these questions, at least the most promising way of answering these questions, would be the discovery of an example of life somewhere else in our solar system (fig. 257) and thereby probably of independent origin.

The solar system has been discussed many times from the standpoints of other disciplines. I would like to comment upon the solar system from the standpoint of a biologist. Skipping Mercury, because I don't think even planetologists can tell us enough about it to permit speculation, we move out from the Sun to Venus. While present data indicate the surface of Venus is too hot to be an abode for

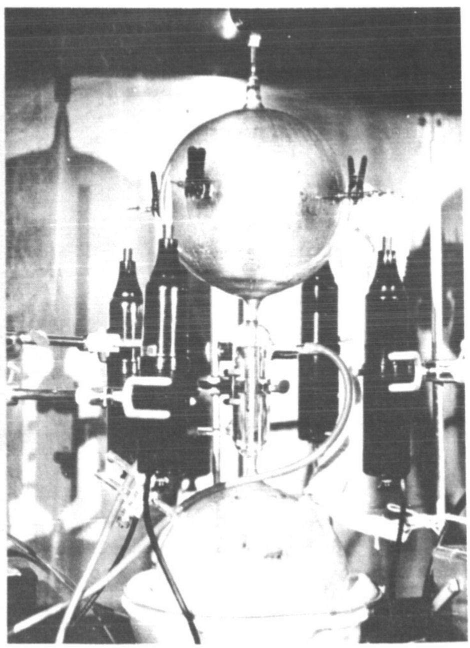

FIGURE 256

THE SOLAR SYSTEM

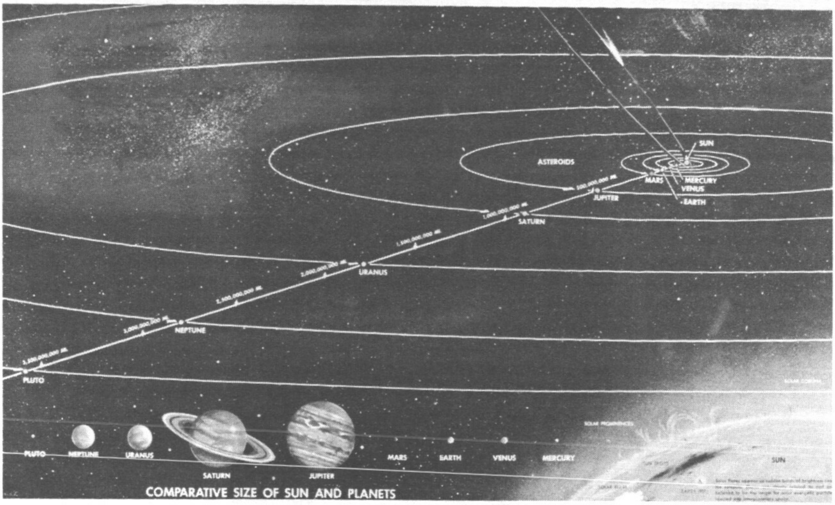

FIGURE 257

life as we know it, biologists are very interested in the exploration of this planet. Earth has been very well supplied with living things for a long time. Abiogenic organic materials were deposited on the Earth in its earlier stage. Most of these materials have disappeared because they have been eaten by living organisms. Earth has a satellite, the Moon, which we are on the threshold of investigating thoroughly. Figure 258 has a little different meaning to biologists than to others who have commented on it. One of the theories about the Moon, and one of the things that makes it most interesting to biologists, is that, contrary to the Earth, the Moon may have served as a "deep freeze," to save abiogenic organic chemicals and thereby provide a clue as to what the prebiotic chemistry was on Earth. There must be carbon there and, if so, we'd like to know in what form. In figure 258, we see for the first time something the biologists have hoped for: a sharp cliff face that apparently goes down several hundred meters. I really long for the day when we can take samples from across that cliff face to find out what may still be in there.

There has been so much said about Mars (fig. 259) in the last few years that I will not discuss that planet again except to say that most biologists think it the most likely site for discovery of extraterrestrial life, because of its similarity to the Earth. A point of great interest, however, is the red spot on Jupiter. In the laboratory simulation of primitive atmosphere (see fig. 256) the gases which are known to make up the Jovian atmosphere and which are known to be quite similar to our imputed primeval atmosphere, on being exposed to an electrical spark produce a chemical reaction which gives off a red glow. The spectral emission coming from the glow is practically identical to that from the "red spot" on Jupiter. It may be that we have abiogenic production of organic compounds in process now on Jupiter similar to that occurring during the early history of the Earth.

Now how would we recognize life on another planet? The four ways to look at this question most simply are from the standpoint of (1) *form and structure*, the classical one that Darwin used; (2) *function or behavior*—i.e., function of enzymes or behavior of organisms; (3) *effect on environment*—the substituted methane suspected in the Mars atmosphere would be of great interest because methane in the Earth's atmosphere is apparently a measure of the Earth's biological activities; and (4) the *chemical composition*. Perhaps one should search for complex molecules and examine their "building blocks" to see if any optical rotation or preference for right or left handed molecules is present. To do all

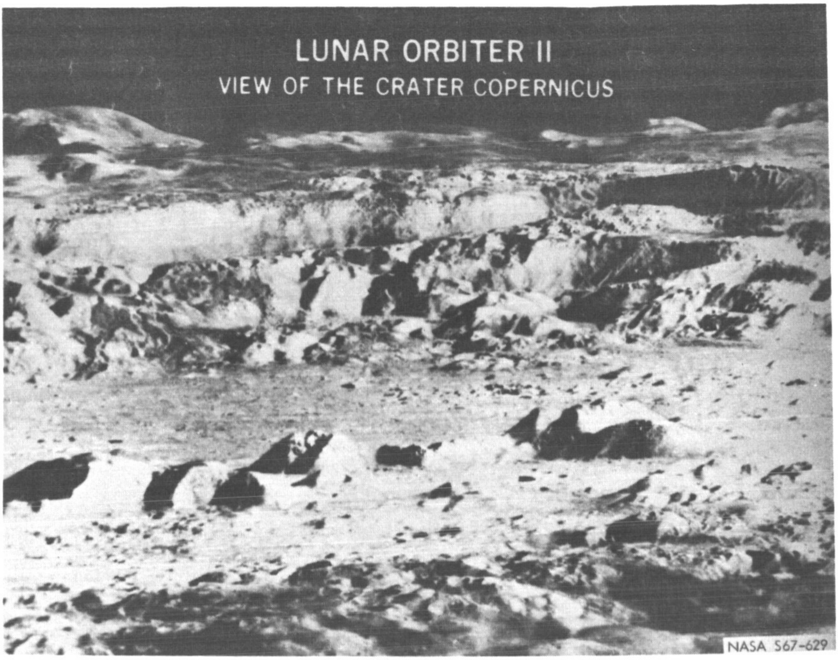

FIGURE 258

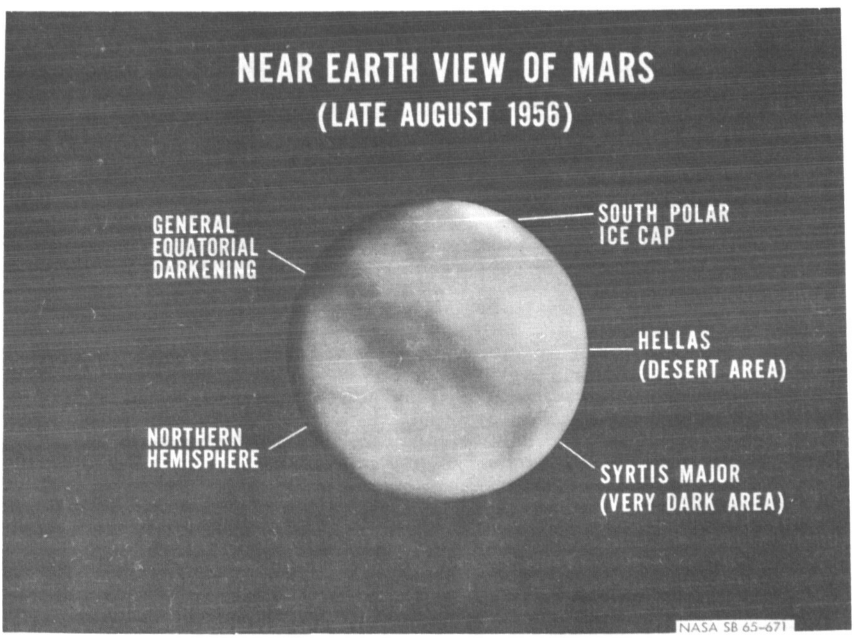

FIGURE 259

these things we can set up laboratories on Earth as laboratory breadboards such as the one at the Ames Research Center shown in figure 260.

When the Challenger expedition went out of England (1872–76) to explore the deep sea bottom, the ship's laboratory (fig. 261) displayed practically all of the tools that we would need to look for life on Mars in the state of the art of a century ago including an onboard library, collecting tools, visual imaging, and chemical analysis apparatus. In July 1893, the Board of Regents of the Smithsonian Institution, in their annual report, stated:

"The expedition of the Challenger will rank as among the most famous ever undertaken in the interests of science. The new and weighty facts which the expedition disclosed, as well as their thorough investigation, are admirably set forth in the published reports.

"For a long time naturalists believed that the existence of any life in the great sea depths was rendered impossible by the enormous pressure and the total absence of light."

If we, in the last sentence, substitute *Mars* for the sea, *low barometric pressure* for "enormous pressure," and *too great a flux of solar energy* for "total absence of light," we have a very stirring statement that may some day be made concerning man's by then historical expeditions to Mars.

In closing, it is significant that the generalizations in biology used today, the scaffolding on which biology has been based in the last hundred years, came from the 3rd quarter of the 19th century. One century after the Challenger's expedition, we are talking about *Voyager* and *Mars*. One of the things that is so enticing to me about that expedition is my conviction that in the 3rd quarter of the *20th century* we will add some more scaffolding to support additional structure in biological science. The search for extraterrestrial life, and the required background research on terrestrial life, lie in the main stream of the study of life, and afford hope for progress of great magnitude in biological science.

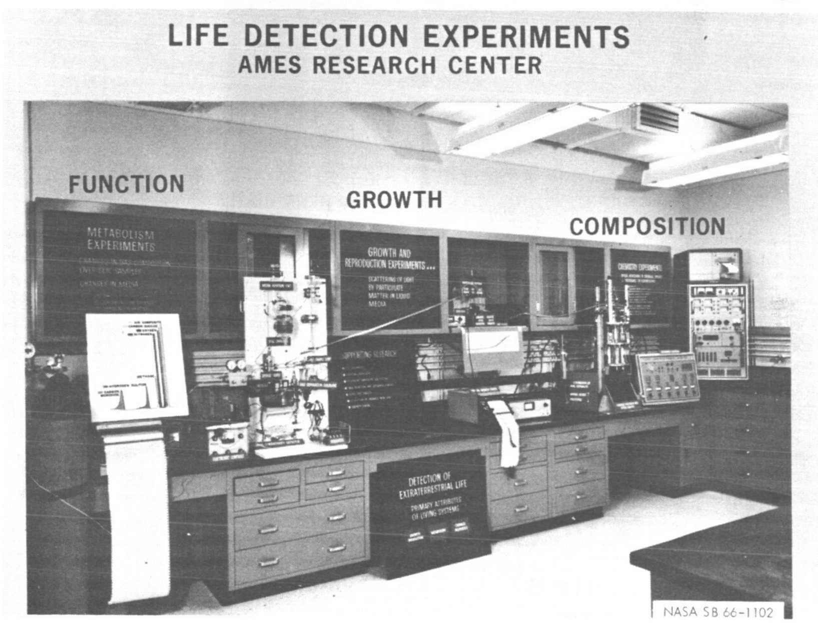

FIGURE 260

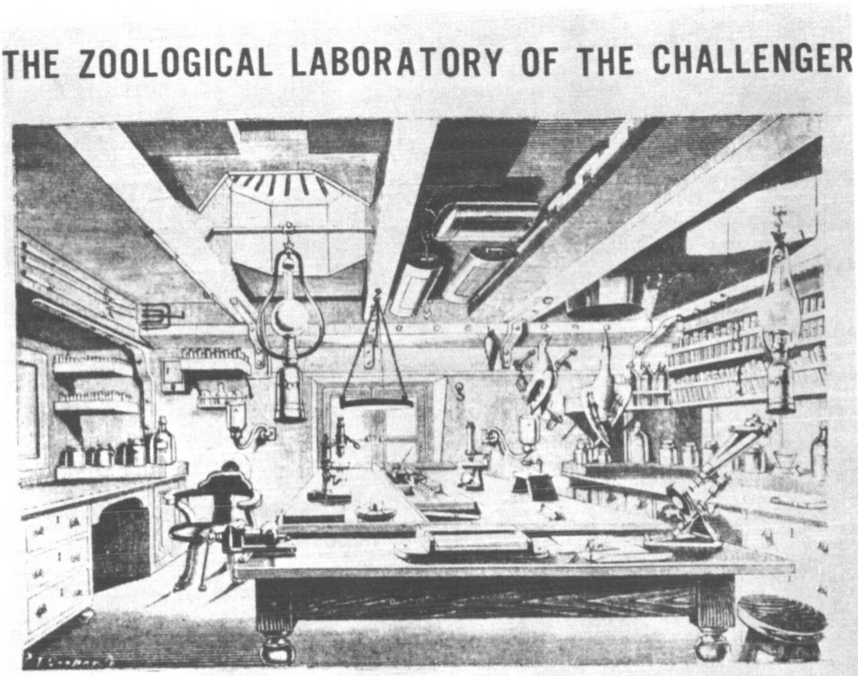

FIGURE 261

APPENDIX IX. WHAT IS SCIENCE?

Homer E. Newell, Associate Administrator for Space Science and Applications, National Aeronautics and Space Administration

It is with considerable trepidation that I attempt in a few brief paragraphs to define what science is. Many authors, themselves illustrious scientists, have undertaken this task, and have considered it necessary to devote whole books to the subject. It is a way of life, not always understood by those who do not live it. Yet, its influence rests upon all of modern society, being seen not only in the objects of everyday living but also in our concepts and patterns of thought. It is important that science be understood, because while it exerts its influence it also seeks nourishment.

The first definition I heard of science was given by a ninth grade general science teacher who said, "Science is classified (i.e., organized) knowledge." That is a simple definition, easily understood, and at the time seemed a good one. But the fact of the matter is that the definition is quite superficial and wholly inadequate to describe what science really is. To be sure, organized knowledge is one of the by-products of science, but science in its full meaning is more, far more, than a mere accumulation of facts, figures, and data.

I have said that science is a way of life. It is what scientists do. It is the process by which scientists, individually and collectively, work together to devise a commonly accepted explanation of the universe about them. It involves observation and measurement, imagination, induction, hypothesis, generalization, deduction, test, communication, and mutual criticism, in a never-ending round of assaults on the unknown or poorly known.

The scientist observes and measures. It is a fundamental rule of modern science that it be based on what actually happens in the physical world. To determine this, the scientist collects experimental data. He makes his measure-

ments under the most carefully controlled conditions. He insists that results of experiments and measurements be both repeatable and repeated. When possible, he measures the same phenomenon in different ways, to eliminate any possible errors of method.

To experimental or observational results the scientist applies imagination in an effort to discern or induce common elements that may give further insight into what is going on. In this process he may discover relationships that lead him to formulate what he calls laws of action or behavior, such as Newton's law of gravitation or the three fundamental laws of motion. It is not enough that these laws be expressed in qualitative terms; they must also be expressed in quantitative form so that they may be subject to further test and measurement. For example, Coulomb's law of the forces between electric charges is expressible in terms of a formula which can be, and has been, checked by experimental measurements which establish the validity of the law.

The scientist generalizes from the collection of observations and measurements, and relationships and laws that he has accumulated. The purpose of such generalization is to try to develop a theory which can in some coherent way "explain" a collection of what might otherwise appear to be unconnected or unrelated results. In seeking such generalization, the scientist requires that the theory be broader than the current state of knowledge about the subject. If the theory is too restrictive, explaining only what is now known and nothing more, then it is of very limited value and basically unacceptable.

The new theory must go beyond the presently known, and predict, by deduction, new phenomena and new laws as yet unobserved. Then these new predictions can serve as guides to new experiments and observations. By taking these new predictions and working them together with other known facts, the scientist can often deduce a result that can be put to immediate test either by observation of natural phenomena or by conducting a controlled experiment. Out of all the possible tests that the scientist might devise in this manner, he attempts to choose those for actual trial that are of such a clear-cut nature that a negative result would discredit the theory being tested, while a positive result would be as strong as possible in favor of the theory.

In this connection, contrary to widely held popular belief, the scientist is not seeking for "*the* theory," the absolute explanation of the phenomena in question. Quite the contrary, it is recognized that under the rules of the game one can never claim to have the ultimate explanation. In testing hypotheses and theories, the scientist can definitely eliminate theories as wrong when the results of a properly designed experiment contradict in a fundamental way the proposed theory. In the other direction, however, the scientist can do no more than show a theory to be *acceptable* in the light of currently known facts. Even a long accepted theory is at any time subject to being at least incomplete, having been based on only a limited body of observations. With the accumulation of more observations and data, the presently acceptable theory may prove incapable of explaining some of the new facts. Then the old theory must be modified or expanded, or even replaced by an entirely new theory embodying new concepts.

So as he progresses in his efforts to push back the frontiers of knowledge the scientist is continually attempting to develop an acceptable "best-for-the-time-being" explanation of the currently available data. As we mentioned earlier, this theory must do more than just explain all the known data. It must be sufficiently broad and penetrating to suggest fruitful new lines of investigation into the as yet unknown. And it must be capable of being subjected to definitive tests as to its acceptability.

In all of this process, the scientist continually communicates with his colleagues in a variety of ways, subjecting his results to the close scrutiny and criticism of his peers. Each observation or measurement is carefully examined and questioned. Each must be repeated and checked sufficiently to assure its validity. Theories are compared against known observations and facts, and against other proposed theories. Nothing achieves acceptable standing in the growing body of scientific knowledge except through this searching trial by ordeal.

We should hasten to emphasize that this is not a process of voting on the basis of mere numbers. Even though the vast majority of the scientific community may be prepared to accept a given theory, a telling argument by a single

perceptive individual can remove the theory utterly from competition. Thus, the voting is carried out through a continuing exchange of argument and reasoned analyses. Those who have nothing to offer either pro or con, in effect do not vote.

The process of communication among scientists follows several avenues. There are the established printed journals, in which working scientists publish papers on their measurements and calculations. Presentations are also made to societies at periodic meetings, at seminars, colloquia, and working sessions, and in informal meetings among scientists.

This last method of exchange has become an exceedingly important one in modern science, in which sometimes the pace of ideas exceeds the speed of the printer. But whatever the method, this ebb and flow of ideas between and among working scientists is an exceedingly important part of what is known as science. Indeed, one author was led to state that modern science *is* communication. Although this statement over-simplifies the total picture, nevertheless it embodies a good deal of truth in that without the communication process, modern science would founder.

Thus, the term science today has a profound meaning. The process or activity that we call science has developed its rules, its body of tradition, on the basis of hard and searching experience. Recognizing that physical science cannot attain the absolute in knowledge, and leaving that to the metaphysicians and philosophers, scientists have sought to substitute for the unattainable absolute the attainable utmost in objectivity. The scientific tradition, while demanding of each individual the maximum of insight, ingenuity, imagination, discernment, and invention, that is the utmost in subjectivity, nevertheless wrings out as much of the personal equation as possible in demanding that the individual subject his thoughts and result to the uncompromising scrutiny of his skeptical peers. This tradition the members of the scientific community accept without reservation. This acceptance gives to science and scientists a unity not only of knowledge but of method that encircles the world and transcends political divisions.

This then is the process by which scientists throughout the world join hands, as it were, in advancing human knowledge. This is the process from which come the knowledge, ideas, and principles used in practical applications of a technical nature. Moreover, just as practical returns stem from scientific research, so does scientific research benefit from the practical results of applied research and development. The achievements in electronics, power supplies, structures, materials, rockets, etc., contribute fully as much to the advancement of scientific techniques as results of science did to make the engineering achievements possible. In this partnership of science and technology and engineering, science plays a role of especial importance to our society.

Appendix X. A Brief History of Research in Electricity

John E. Naugle, Deputy Associate Administrator for Space Science and Applications (Sciences), National Aeronautics and Space Administration

The history of the discovery, understanding, and use of electricity covers 2500 years and involves many people from many countries. For the first 2400 years the people who studied electricity were motivated by a desire to understand a peculiar natural phenomenon. The practical value of the knowledge they were accumulating—the work for man which electricity could do—was not recognized until the mid-19th Century. The recognition of the value of electricity, and of the research which led to man's understanding electricity, profoundly altered man's environment and his understanding of the potential value of scientific research. The discovery and understanding of atomic energy is also altering man's environment and has made him acutely aware of potential hazards to that environment from the improper application of scientific knowledge.

The sentiment in the country appears to be tending away from the support of basic research toward the practical application of existing knowledge to solve existing problems, motivated perhaps by the magnitude of those problems and by a fear of the results of scientific research. At such a time it might be well to review the history of the research into electricity to see if there are lessons we can learn which will help us make the right decisions today.

The recorded history of the research on electricity starts with Thales, a Greek philosopher who, in 600 B.C., discovered that rubbing a piece of amber

over a cloth made it attract small particles. It is from his work that we get the name "electra," the Greek word for amber.

Little additional knowledge of electricity was obtained from the time of Thales until after the renaissance and the beginnings of modern science in the 16th Century. Modern science, with its emphasis on accurate, recorded, and published observations and on the exchange of information among scientists, enabled scientists to understand and extend the work of their predecessors. Scientists began the systematic study of electricity in the early 1600's when an English doctor named Gilbert made observations of the materials which could be electrified, and recorded his results. With one exception, the tools available to Dr. Gilbert were very simple: amber, and a variety of natural materials such as cat's fur and silk. The exceptional tool, of course, was the questioning human mind which was then and is now the most important tool in scientific activity.

One hundred and thirty years later the Englishman Gray extended Gilbert's results to show that this "electricity" could be conducted along metallic surfaces. Shortly thereafter a Frenchman named Dufay showed there were the two kinds of electricity which we now call positive and negative charges. At that time people regarded electricity as a kind of fluid which they tried to store in various kinds of containers. Dr. P. van Musschenbroek of Leyden found it could be stored in a device which we still call a Leyden jar.

At about the same time an American, Franklin, showed that lightning was related to electricity.

Throughout the period from the early 1600's to the late 1700's, scientists were engaged primarily in observing and recording their observations of the behavior of electricity.

Coulomb, a French scientist, designed a sensitive torsional balance in 1777. He began to use this torsional balance in the 1780's to study the force between electrical charges. He found that the force between two electric or magnetic charges was directly proportional to the product of the charges and inversely proportional to the square of the distance between them. Physics students today learn Coulomb's laws of electrostatic electricity in their first course in physics.

Additional knowledge of electricity was contributed by two Italian scientists, Volta and Galvani. Galvani related electricity to animal behavior. He showed that if the nerve of a frog was connected to one metal and that metal to another metal and if the second metal was then connected to the muscle of the frog, the muscle would twitch. From the work of Galvani and Volta ultimately came a device for producing a continuous flow of electrical current, a battery, as well as new insights in biology.

Another Englishman, Davy, in the early 1800's related electricity to chemistry, when he showed that one could use an electrical current to separate water into hydrogen and oxygen.

The next contribution was a major one by Oersted, a Dane. For the first time he linked electricity and magnetism together by showing that an electric current generated a magnetic field. A Frenchman, Ampere, took up Oersted's work and developed a new concept of magnetism and also introduced the concept of tension in an electrical circuit, or voltage as we know it today.

A German physicist named Ohm worked out the relationship between the voltage, current, and resistance of a wire carrying a current.

About 1821, an Englishman, Faraday, began to experiment with electricity and really extended the knowledge of electricity. In those days people had been looking for ways to make electricity from magnetism. In 1831 Faraday proceeded to do so. He discovered that he could generate a voltage by moving a conductor through a magnetic field. In a period of about 10 days he conducted a series of experiments which conclusively demonstrated the existence of electromagnetic induction.

Faraday for the first time began to see a practical use for all this knowledge of electricty. He was asked in Parliament what the value of his research on electricity was, and he answered, "Someday you will tax it!" He was a little premature, but not much.

Another Englishman, Maxwell, had to make his contribution before full use could be made of electricity. Maxwell studied the work of Faraday, the laws of Coulomb and Ampere, and put them together into what we today call Maxwell's four equations, which we still use to predict the behavior of electricity. From those equations he predicted the existence of electromagnetic waves traveling at the velocity of light.

About 1850 a vast amount of knowledge about electricity was available. As the scientists continued their research, many other people began to apply the knowledge that had become available over the past 250 years. By 1880 Edison in America, and Lane-Fox in England, developed the first supply of electricity.

Hertz investigated the prediction of Maxwell and showed how to generate radio waves.

By the early 1900's Marconi was telegraphing messages across the Atlantic. Man had a new means of communication, a new source of light, a method of transporting the energy of a waterfall to a city, and a multitude of powerful machines to free man from the drudgery of routine work.

The history of electricity continues today. One can follow the thread of research on the nature of electricity through the study of the electron, and on to the work that is going on today.

What can we learn from this brief and very superficial history of electricity?

First, it took many men from many countries 250 years to develop sufficient understanding of electricity to put it to use for man. After the scientific knowledge was available, it took another 30 years to develop the first practical applications.

Secondly, it involved the scientific disciplines of physics, mathematics, chemistry, and biology. It was impossible to predict who would make the next discovery or even in which discipline the discovery would be made. Maxwell needed all the mathematical tools then available—calculus, vector and tensor analyses, and partial differential equations to derive the laws of electromagnetism.

Thirdly, the work proceeded even in the face of violent turmoil in Europe. Ampere and Coulomb, for instance, did their work while France was in the throes of a revolution.

Fourthly, if any country had recognized the practical value of electricity early in its history, it would not have been able to accelerate its development except by supporting work in all of the scientific disciplines because it would not have known in which discipline the next crucial discovery was required. Conversely, no single country could have greatly impeded the progress of the research. Only a concerted effort on the part of all the rulers of Europe to halt research, to prohibit the publication and exchange of information among scientists, and to stop the teaching of the physical sciences could have had a marked effect on the progress of research. To do so would have produced another dark age in the history of mankind similar to that which existed in the Middle Ages.

Finally, the history of electricity is not completed even today. Scientists attempting to understand the nature of electricity discovered the electron, the proton, and the neutron, and as they began to understand these particles they began to recognize a new application of this knowledge—atomic energy. The effort to understand electricity continues today in many laboratories, most particularly at the Stanford 20 Bev electron accelerator.

Although there are many more scientists today working with vastly more complex equipment than there were in the 18th and 19th Centuries, the problems they are attacking are correspondingly tougher. An individual can no longer solve the problem with equipment he builds in a university instrument shop. Support must be provided by national governments.

We cannot foresee the practical benefits, nor the problems which will come from today's scientific research. We can be sure that as long as men are born with a questioning mind and access to the knowledge and techniques of science they will ask new questions of nature, evolve new theories, and further expand our knowledge. If this nation should turn away from the support of basic research, either because of a desire to get on with the practical problems, or because of a fear of the results of scientific research, we may very well lose on both counts. We may deny ourselves the very knowledge required to solve those practical problems, and unless we can persuade all the other countries of the world to stop their support of basic research, we will not avoid the results of scientific research. In addition, we will be in a relatively poor position to deal with them because of ignorance.

We must both continue the support of basic research to provide the new knowledge and broaden the support of the efforts to understand the benefits and hazards which attend this knowledge.

APPENDIX XI. PRACTICAL RESULTS FROM THE NASA SPACE PROGRAM

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The purpose of this document, for the fourth consecutive year, is to summarize some of the latest practical advantages deriving from the space program's broad scientific and technological advances. This sort of benefit is increasingly emerging from the program, but what is far more impressive and significant is that whole new technological systems are now being acquired with so many potential applications, in such a wide variety of aspects of our daily lives, that only a few of their more obvious possibilities can be highlighted.

Wherever a proliferating development can be pointed out, the individual topics have been presented in more detail than was given last year. Consequently, the items shown here have been deliberately selected from the much larger group of new items that have appeared during 1966, in order to give a more comprehensive appreciation of their present or impending worth.

Your attention once again is invited to the fact that many of these practical advantages would not yet be apparent, probably, if they had not been discerned as early and publicized as quickly as feasible through NASA's Technology Utilization Program. As you know, its purpose is to make available to the nation's economy at the earliest possible moment those technological developments that may be of value outside the space program as well as in it.

Many individuals at NASA Headquarters and field centers have contributed the mass of reports from which the following items were selected. A majority of the contributions came from the Goddard Space Flight Center, the Jet Propulsion Laboratory, Lewis Research Center, and Langley Research Center. And although the items naturally represent, for the most part, those practical advantages stemming from programs of the Office of Space Science and Applications, they do include both present and anticipated benefits from the entire space program.

The items are arranged under general headings, such as National Security, Industry and Manufacture, Earth Resources, etc. It will be noted, however, that choosing a category for some of these topics has had to be a purely arbitrary decision, since they could almost as well have fitted into several other categories. In particular, many of the items in other categories contribute to National Security, accounting, in part, for the brevity of that section.

As on earlier occasions, the examples start with those that pertain primarily to our National Security.

NATIONAL SECURITY

1. The shipment of Chinook helicopters urgently needed in the Vietnam war zones has in some cases been delayed because conventional techniques were incapable of removing dents made in hollow-blade spars during fabrication. Boeing's Vertol Division and NASA's Marshall Space Flight Center are now working together to design and construct for this urgent job a tool that is an adaptation of the successful Electromagnetic Hammer, developed at MSFC to remove dents from welded tank components for Saturn rockets.

2. A unique seismometer designed to withstand the extremely high impact shock of a hard landing on the Moon and telemeter its subsequent measurements back to the Earth is now being marketed by Teledyne Industries. The device can be dropped to a remote terrestrial location by parachute or even by free fall. It has large potential value as a means of monitoring underground nuclear tests. In addition, the device can be used to study the response of large structures to earthquake tremors or blasting shocks.

3. A new type of stretcher was developed by a NASA contractor to lift an injured worker vertically out of a Saturn fuel tank through a narrow opening in the top. Essentially the same means could be used to hoist wounded soldiers from a battlefield to a hovering helicopter unable to land. The stretcher is lowered by crane, placed around the patient with straps and padding that will keep him comfortably immobile during all carrying operations, and raised straight up when he is snug and secure in it.

4. Liquid methane has been analyzed and found highly promising as a possible fuel for supersonic aircraft. Its heat of combustion is 16 percent higher than that

of conventional jet fuels, its use would not enforce any major redesign of present turbojet or turbofan engines, and it is readily obtainable from natural gas. The use of liquid methane for fueling military and commercial jet aircraft might increase the carrying capacity of the planes and reduce operating costs as much as 30 percent.

5. A foldable metal tubing has been developed that can be sharply bent or rolled into a compact coil for launching in a rocket payload, and is then capable of erecting and expanding itself upon release. The tubing has many apparent uses, as, for example, in foldable helicopter blades, fluid conduits, foldable and portable scaffolding, and in self-erecting rigid structures that can be reused repeatedly.

6. An automatic living-cell analyzer for recognizing patterns of possible life forms on Mars can be modified for significant uses in counting blood cells on Earth. In the event of an atomic disaster, it would be imperative to the nation to identify quickly those who could be saved. This automatic analyzer can provide almost instantaneous blood counts reflecting the degree of radiation damage incurred, and thus the relative chance of recovery.

7. Supersonic wind-tunnel studies of the various wakes behind a number of different wedge-shaped bodies have provided much specific information about the features of flow that are characteristic of each shape. This information is of obvious value in radar recognition of the wakes of bodies entering the Earth's atmosphere, and should be important to our ballistic missile defense system.

8. Techniques of pattern extraction that have been developed to improve television pictures from spacecraft cameras can be applied to two-dimensional seismic detection and location of field artillery pieces that shake the ground by firing.

9. The compound hydrazine diborane is a high-energy, solid monopropellant that has long been of interest to the space program. It stores well and can be handled safely with normal precautions. One of its outstanding properties is the fact that it contains more hydrogen per unit volume than liquid hydrogen does. Furthermore, all of this hydrogen is released by combustion. Two commercial firms are currently attempting to develop the use of hydrazine diborane as packaged gas for military balloons.

10. Current progress in the technique of sterilization has led to the development of solid propellants able to survive prolonged exposure to sterilizing temperatures of 275 degrees Fahrenheit. It seems likely that solid propellants of this nature could be used in missiles to be mounted on the outside of high-speed aircraft, whose external skin temperatures rise significantly in flight.

11. Closely correlated theoretical and experimental studies of how the layer of air surrounding a high-speed missile or airplane wing goes from a laminar form to a turbulent one have been made. This phenomenon is of enormous importance in designing supersonic aircraft and missiles for predictable performance. From these studies may come a reliable and perhaps improved method for designing aerodynamic bodies for the best possible high-speed airflow characteristics.

INDUSTRY AND MANUFACTURE

Before beginning the recital of some of the outstanding present or imminent practical benefits of the space program to industry and manufacture, it is appropriate to quote briefly from a pertinent letter. Always before, participants in the space program have expressed the personal conviction that the practical advantages that are envisioned from the scientific and technical progress would seem equally promising to industry. A meaningful bit of testimony from industry's side supporting this view follows.

The letter referred to is from Dr. Edwin G. Schneider, Vice-President-Engineering, Sylvania Electronic Systems. Dr. Schneider, who points out that he speaks from extensive experience with Department of Defense contracts as well as with NASA's, says in part: "It is my belief that the technology being developed under NASA and DOD contracts is being applied to commercial products at a rate which is limited only by the ability of engineers to assimilate the knowledge and the ability of industry to carry new product ideas all the way through to the market place . . . The concern expressed by various groups over the apparent lack of transfer of technology from NASA and DOD appears to me to be based on an imperfect understanding of the engineering process and an unwarranted expectation that much of the transfer will be easily recognizable as

hardware end items." Dr. Schneider identifies publication of new information in the technical literature, interchange of duties of commercial engineers between government and nongovernment work, and the stimulation by government to industry to support their own development of new and more capable devices as being the primary means of transfer. These comments confirm the belief that much transfer occurs that is not and really never can be identified. The listing serves to provide easy credibility that this much greater degree of transfer is actually being accomplished.

Here are some of the latest examples of space-generated technology that have obvious application not only to industry and manufacture but to many other aspects of our lives.

1. NASA's stringent spacecraft requirements and resulting space research have instigated the development by industry of strikingly miniaturized computer circuits, which in a short time will find their way into commercial machines, providing important savings in space and cost and gains in reliability. Computers have been scaled down to the astonishing point where thousands of circuits can be compressed into a case smaller than a quarter of a dollar, and the equivalent of a large machine can occupy only a cubic foot of space.

2. Stable metal alloys have been developed at Lewis Research Center that dramatically increase the resistance of bearings to catastrophic wear when their surface film of lubricant fails. The secret lies in tailoring alloys so that they have a hexagonal crystal structure of atoms instead of the customary cubic crystal structure. Hailed by a research magazine as one of the hundred most significant industrial developments of the year, this technology can be expected to reduce the incidence of bearing failure, or completely eliminate it, in the event of brief loss of lubrication. These new alloys, because of their low friction and noncorrosiveness, should also be valuable in making artificial hip and elbow joints.

3. An air brake-dynamometer has been devised that can absorb and measure the power output of rotating machinery over an extremely wide range of shaft speeds, from 0 to more than 75,000 rpm, and over a broad range of power. It can also be used as an air turbine or air motor to produce shaft power at many different speeds and torques in both clockwise and counterclockwise directions. One company has already applied to NASA for a patent license and design drawings to manufacture a line of these devices.

4. Very close temperature control in lightweight preheaters for space-power systems has been achieved by mixing pyrotechnic powder with selected materials that change phase at the desired temperatures. The pyrotechnic heaters, developed for a NASA experimental program, are now being marketed.

5. A method of ion plating has been devised for depositing thin films on complex surfaces in a single operation without moving the object being plated. A strong bond is formed between film and substrate, since the surface is continuously cleaned both before and during the process of deposition. This method of plating with high-energy metal ions is important in cases where conventional vacuum techniques for depositing thin films fail.

6. An interesting new computer program can be used to analyze and study combustion processes and help design equipment for furnaces, combustion engines, chemical reactors, and the like. Devised to compute chemical equilibria in complex systems, the program requires only a simple input, does not need initial estimates, and can handle up to 15 chemical elements and a total of 90 reaction products, including condensed species.

7. In developing a valve sensitive enough to detect the slight increase in oxygen pressure resulting from the exhalation of plants in a biosatellite experiment, a mechanical device has been created that uses magnets as the valve. This promises many uses in industry wherever a cheap, sensitive valve is needed to guarantee the release of accumulated gases at the slightest increase in pressure.

8. A technique has been developed that enables a general-purpose pump of large capacity, coupled with analog controls, to simulate the operating characteristics of a wide range of other pumps. This apparatus, when connected to a pumping system, can determine which of the available standard pumps would be best suited to a specific purpose.

9. The applications of tungsten have been limited by the metal's very poor ductility at room temperature. It is known that adding a substantial amount of rhenium to tungsten creates an alloy with extraordinarily improved ductility at room temperature. Further research has now revealed that tungsten-rhenium

alloys with considerably smaller amounts of rhenium in them have significant ductility at low temperatures. The high cost of rhenium makes this discovery valuable, and the research results should make possible additional use of tungsten.

10. A unique transducer developed to meet NASA's needs for measuring temperature in inaccessible places is now being marketed in considerable quantity. The transducer, which advanced the state of the art in output, size, voltage, and stability, generates a signal proportional to ambient temperature. It is of value to many industrial processes, laboratory measurements, and telemetry.

11. A cold-cathode ionization gauge devised to measure extremely low pressures on satellites is now finding a wide market in metal, chemical, packaging, and food industries. It is also being sold for use in thin-film semiconductors and insulators, and in scientific apparatus, such as high-energy particle accelerators.

12. Advances in the techniques of drawing fine wire have resulted in the production of niobium wire only 100 angstroms in diameter. (An angstrom is one ten-billionth of a meter.) Continuous wire of this remarkable fineness, with electrical and mechanical integrity, has been produced in lengths of up to six inches. The techniques involved should be of benefit to the technology of composite materials, such as fibers, and also to biomedical research and applications.

13. For measuring the absorption, emission, and temperature of gaseous products of hydrogen and oxygen combustion, a radiometer-pyrometer has been developed that measures radiation from as many as six bands of wavelength, from ultraviolet through infrared. Since the radiation bands are selected by means of readily changed filters, this instrument has wide utility and can serve either its original purpose or as an analyzer of other high-temperature gas mixtures.

14. NASA's Special Publication 5053, entitled "Conference on Selected Technology for the Petroleum Industry," has sold more than 9,000 copies since the Government Printing Office offered it for sale last July. This publication contains the proceedings of a NASA-sponsored conference that was attended by 250 executives of the petroleum industry. The conference was another in a series that NASA arranges periodically to communicate to a single industry a comprehensive awareness of space technology. Since this particular conference, there has been a striking upsurge in the number of petroleum companies participating directly in NASA's Technology Utilization Program, a rise in the number of interested queries from other companies in the industry, and a marked increase in the attention paid to space program technology in the industry's own publications.

15. A ruby laser developed for the dynamic balancing of gyros for space use is now commercially available. The laser can machine a gyro rotor while the gyro is spinning at speeds up to 24,000 rpm.

16. A vacuum collector head that can be attached to a mill or a lathe and catch most flying chips and particles was devised for work with solid propellants, whose fragments are dangerous because they are combustible. It is plain that the collector head would be useful in machining radioactive as well as explosive material.

17. A significant new series of solid propellants of a type called Saturethane has been formulated in the process of meeting requirements for withstanding cycles of high temperature in sterilization treatments for space use. This new type of propellant uses a urethane-cured, saturated hydrocarbon binder, and has demonstrated its ability to retain unusually good mechanical properties after repeated 53-hour exposures to 275-degree heat. The binder system may be applicable to industrial uses where it is desirable to retain tough, rubbery properties throughout prolonged high temperature.

18. There has been widespread commercial interest shown in a process developed to form organic polymers by means of isostatic or hydrostatic compression into shapes suitable for tests of their mechanical properties. The process is applicable to a broad range of powdered materials and to metallic and inorganic particles as well. It could be used, for example, to form bearings out of mixtures of powdered polybenzene, teflon, graphite, and the like; or make gears, other machined parts, and electronic components out of powdered aluminum or other metals and fillers. The process could also be easily automated.

19. Development of improvements in advanced metal-joining techniques, such as electron-beam welding, explosive welding, and diffusion bonding, could lead to the fabrication of more complex metal shapes than previously.

20. Studies of the energy-absorption capacities of balsa wood and honeycomb structures may lead to safer packaging and better cushioning of elevators and automobiles against accidental high-energy impact.

21. The needs of the space program for long life and reliability in solid-state electronic components has brought about better understanding of the processes involved in their manufacture, and consequently a higher yield of satisfactory components from automated manufacturing processes. It can be foreseen that low-cost solid-state computers more and more will find their way into the control of airplanes, passenger cars, buses, trucks, construction and mining equipment, and various types of industrial machinery.

22. A new method of vacuum coating was developed to deposit a film of aluminum on a mirror 23 feet in diameter—the largest metal mirror in the world—created for the Jet Propulsion Laboratory's solar simulator. The technique used a single electron beam as a heat source and utilized magnetic "steering" to control the dispersion and deposition of the aluminum cloud, from distances up to 25 feet. The new method could be used widely in the vacuum-coating field, in applications ranging from the production of thin-film electronics and optics to the deposition of corrosion-resistant and decorative films on continuously moving webs of metal and plastics.

Furthermore, the 23-foot mirror's weldment was simultaneously stress-relieved and sagged into final shape. Thus, controlled "creep" forming offers an acceptable method of finishing large aluminum welds to close tolerances. Finally, the mirror's hard nickel surface was electrodeposited while the mirror was mounted on the grinding and polishing machine. The consequent reduction in tooling slashed over-all plating costs to about one-fourth those of conventional plating methods.

23. Construction of a large hydrostatic bearing as part of the 210-foot antenna at Goldstone, Calif., built for deep-space communications, has successfully demonstrated that hydrostatic bearings can be used to rotate millions of pounds of loads smoothly and precisely. The techniques of analytic design originated for this development should help in the construction of large precision machinery of many kinds, including cranes and telescopes as well as antennas.

24. Studies of slurries of solid propellants should benefit manufacturers of asphalt, paint, polymer latexes, and carbon-black-filled rubber goods, all of whom will profit from techniques developed to show the dependence of properties on filler content. The viscosity increase, for instance, will be governed by the maximum amount of filler that can be incorporated. This simple but long-overlooked concept can be expressed mathematically.

25. Improved understanding of rocket heat transfer and fluid physics can be applied to the design of plasma torches, such as those used for flame-spraying and metalizing processes. Also, studies of nozzle heat transfer may be utilized in developing improved industrial turbine designs.

26. An improved nuclear-magnetic-resonance spectrometer, which can be used with nitrogen, carbon, boron, and phosphorous nuclei, should find many industrial applications in the analysis and process control of various fluids and gases.

27. Development of superconducting alloys for cryogenic gyros will permit further miniaturization of computer memory elements and the creation of small electromagnets of high-field strength.

28. An automatic lens design computer program used by the Jet Propulsion Laboratory to design star-tracker and other lens systems could prove very useful to optical design companies. With this program, the companies would be able to produce better lens systems at less cost than by classical methods. They could rent the necessary computer facilities if they didn't already have them.

29. Studies of outgassing on plastics and rubbers have revealed a large variety of impurities in the materials. Being able to identify such impurities and develop means for reducing their incidence in the manufacturing and processing of materials in which small impurities can be dangerous will benefit many industries that have stringent engineering specifications for polymers. These include the food-packaging industry and automobile manufacturing. They also include industries making surgical implants and dental applications.

30. Techniques used to make instruments and equipment rugged enough to survive high-impact landings involving loads of as high as 10 000 g's can be applied in a host of everyday ways. Crash recorders for aircraft and ground vehicles can be made far more durable than they are now. Rescue gear and fire-fighting equipment can be made sufficiently tough to be dropped from planes with a minimum of parachute braking and cushioning. Oil-field equipment can be made sturdier for severe handling. Cameras and transistor radios and tape recorders can be made tough enough to survive any common fall.

31. Many plastics are being formulated that have long-term stability at 600 degrees Fahrenheit and short-term stability at temperatures as high as 1000 degrees Fahrenheit. These could find applications wherever the inherent properties of plastics as these temperatures are more desirable than those of metals or ceramics.

32. A variation of one star-tracker lens might be advantageous in the television industry. It has an image plane opposite in curvature to that of a normal lens, thus allowing the image to be presented directly on the photo cathode of an image-dissector tube.

33. A new class of polymers, called Pyrrones, has been developed that is more resistant to radiation damage than any previously available polymer. It also has outstanding stability at high temperatures, can be tailored with an unusual range of electrical properties, and can be readily fabricated in a wide variety of forms. Though still under development, the new polymer is being considered by industries and government organizations for many uses. It could serve, among other purposes, as a radiation-resistant binder for destruct-system explosives in nuclear-powered spacecraft, as a protective coating for titanium against corrosion and heat on supersonic airplanes, as a high-temperature-resistant cloth fiber for high-speed decelerators as an electrical semiconductor, and as a heat- and radiation-resistant dielectric for electrical and electronic equipment.

34. Research in composite flexible materials for expandable space structures has been applied and extended by one manufacturer to the creation of a 500-gallon flexible fuel tank. The tank is expected to weigh only one-half or one-third as much as those in present use for bulk fuel storage and as external tanks for extending aircraft range. It represents the first successful application of rubber-impregnated filament glass to the fabrication of high-strength, flexible filament-wound structures.

35. NASA has developed a miniaturized memory device with increased storage capacity that can replace tape recorders previously used for this purpose on board meteorological satellites. A computer utilizing the new miniaturized memory device is now being marketed.

36. A machine for testing tensile strengths that was built by Goddard Space Flight Center for its own tests of the strength of adhesive bonds between layers of laminated materials is finding a commercial market. In this machine, stainless steel rollers hold the test specimen in proper position for continuous application of a perpendicular peel force.

37. A connector seal that incorporates a gasket in the form of a metal disk compressed between two serrated edges serves as a positive seal for fluids at temperatures ranging from close to absolute zero to plus 300 degrees Fahrenheit. It is also effective for use in deep vacuums. The connectors can be easily fabricated, with simple tools, from readily available standard stock. One company is already marketing them.

38. A new torque filter provides a constant torque output from a pulsating input. This filter not only smooths angular displacements but eliminates backlash. It can be used in many servomechanical applications employing gear-train assemblies. The filter is soon to be in commercial production.

39. Among the many solid-film lubricants investigated for use on spacecraft is an electrolytically co-deposited film of nickel molybdenum disulfide. A large automobile manufacturer has applied the film to aluminum dies used in forming the rubber molding around car doors. The previous mold lubricant had been a silicone compound, which broke down quickly at the temperature of the molding operation and would not release the molds properly. The new solid-film lubricant has demonstrated that it can function much longer at the same temperature.

40. A miniature fuel cell has been devised for disposing of hydrogen and oxygen gases within closed areas. It is currently being used to consume gases evolved from electrochemical storage cells and to prevent excessive pressures from being built up. The fuel cells can be made as small as pencil erasers or as large as rates and capacities of gas consumption dictate. They should prove useful in many areas of technology for the controlled removal of unwanted gases. In addition, they could serve as detectors of undesired gases in systems for purifying chemicals.

41. Interference-filter wedges produced by NASA have already been used successfully in airplane and balloon instruments, providing a simple, small, highly efficient device for spectrometers. These wedges make possible the manufacture

of spectrometers for chemical and organic analysis and for industrial control that will be far smaller and more efficient than existing instruments and allow much more rapid processing of samples than is currently possible. Two promising applications would be in fast and accurate monitoring of impurities in industrial chemicals, and in checking air pollution in factories.

42. A 256-bit memory device with both read-in and read-out circuitry is being fabricated on a silicon chip only one-fifth of a square inch in size. This development can lead to the creation of an extremely compact, low-power, pocket-size electronic calculator, no bigger than a cigarette package.

43. Development of a precision heat-flow detector for use on the lunar surface may be valuable for remote-sensing in industries that require high-precision thermometry measurements. The detector could also be of value in improving instruments for primary and secondary standards.

CONSTRUCTION INDUSTRY

1. Thanks to an idea borrowed from NASA launch-facility design, San Diego is to have a complex of nine circular apartment buildings, 18 to 24 stories high, that will revolve every three hours, providing all tenants with a full panoramic view. Each building will be rotated by a central service axle mounted on a hydraulic bearing system.

2. The use of Space Age Technology has enabled aerospace contractors to underbid established shipbuilders for a big Navy contract for the design and construction of from 15 to 40 fast new cargo vessels, costing $30–$40 million apiece. A substantial advancement in shipbuilding practices will undoubtedly be one of the lasting benefits.

3. The gold-spray coating used to control the absorption and emission of radiant energy in spacecraft and on the helmet visors of Gemini astronauts can be used effectively and economically to filter solar energy from office and house windows. A transparent gold coating only four-millionths of an inch thick reflects more than 60 percent of the heat energy normally penetrating windows. This reduces costs for air-conditioning, shades, and draperies, while at the same time enhancing the appearance of buildings where it is applied.

4. Now that lasers have reached the practical stage of development, it is possible to use them in distance-measuring equipment based on the propagation time of light beams. This equipment can be faster, more compact, more accurate, and more powerful than any instrument previously available for the purpose. It has clear potentialities in the field of surveying.

5. Hail-resistant panels and methods of testing structures for their ability to withstand hailstorms have been developed as a result of hail damage to one of the 85-foot antennas of the deep-space communications network at Johannesburg, South Africa. The design and fabrication techniques used to solve this problem could be applied to reducing similar damage to buildings and other structures elsewhere.

6. A self-propelled penetrometer, for use either tethered or untethered, should prove to be a valuable tool for geophysicists and soil-mechanics engineers. The tool is an auger that propels itself through soils, making continuous measurements of soil mechanics and other characteristics of soils as it goes. This instrument could eliminate the need for bore holes in many localities, and could both determine soil characteristics and obtain soil samples at underwater locations and beneath buildings.

7. Advanced methods for obtaining both static and dynamic analyses of aerospace structures have immediate application in civil engineering and architecture. The techniques are in the form of computer programs, and would provide designers of civilian structures with an expanded choice of structural shapes, more efficient use of expensive building materials, and reduced need for testing models.

8. Space-program needs have fostered the creation of very high-grade adhesives strongly resistant to ultraviolet degrading. These adhesives could be utilized in coatings to reduce weathering of bridges, houses, and other structures. The coatings would require little or no maintenance after being applied.

9. Adaptation of the technology of white coatings to large petroleum storage tanks could reduce boil-off losses by reducing storage temperatures. The same technology could also be applied to the exterior finish of houses and other buildings, reducing the requirements and operating costs for both heating and air conditioning.

10. "Heat pipes," new devices developed in nuclear-power research that transmit high thermal-flux densities with little loss, may be used to convey heat through air-comfort systems for houses and commercial buildings as well as in manufacturing processes.

11. A stick control system for the six independently powered electric drive wheels on the mobile lunar laboratory developed at Marshall Space Flight Center could be utilized in large earthmoving equipment with drive wheels that are independently powered by electric motors.

12. A spray-coating devised to control heat on spacecraft sharply reduces its absorption of solar energy at a selected design temperature. The coating has an opaque, diffuse white surface until it heats up to design temperature, whereupon it gradually becomes transparent through a phase change, and exposes a highly specular subsurface with only half the solar-absorption characteristics of the original surface. This brings a quick reduction in temperature. The technology involved here could have valuable application on ground vehicles and structures.

13. An automated system is being perfected for generating the best specifications for many types of construction. The system is based on the tape storage of a comprehensive catalog of approved construction specification "bits," from which combinations appropriate to each construction project may be ordered as an organized print-out of specifications. The system would greatly reduce the time requirements of specification writers, stenographers, printers, estimators, and the like. It has obvious potentials in other fields of procurement and in civil applications.

14. Observations from Earth satellites should provide valuable data for geologists, geographers, civil engineers, and other planners involved in the selection of sites for dams and highways, bridges, nuclear reactors, pipelines, public buildings, and large private structures. Study of infrared imagery of wide regions from spacecraft reveals such potential hazards as landslide areas, fault zones, and unstable water-saturated soils or fill.

COMMUNICATIONS

1. NASA's successful Syncom satellite demonstrated that a global communications network is feasible through the use of satellites in Earth-synchronous orbits. Congress, as you know, created the Communications Satellite Corporation for the purpose of establishing such a network. Comsat's first commercial communications satellite, Early Bird, based on the Syncom design, has been operating successfully over the South Atlantic since April 1965, linking North America with Europe. In cooperation with the 52 foreign powers that are its partners in the International Telecommunications Satellite Consortium, in which both governments and private interests are represented, Comsat now is in the process of improving and expanding the network.

Two new communications satellites, more than twice as powerful as Early Bird, will extend commercial satellite communications to two-thirds of the world. One is already in position, though not quite in its intended orbit, over the mid-Pacific. The other will be located over the mid-Atlantic, multiplying the present number of communications channels between North America and Europe and making possible similar links between Latin America and Africa. These new birds, called Intelsats, will be the world's first communications satellites that can be utilized by several land stations in different countries simultaneously. For instance, the forthcoming Atlantic satellite will enable stations in Great Britain, France, West Germany, and Italy to receive individual messages from the United States at the same instant without interference. This satellite will also permit television programs to be relayed without pre-empting channels needed for telephone or data transmission.

NASA provides launch services for Comsat at a charge of $3.5 million each.

2. The photosensitive, field-effect transistor used in transmitting pictures from space satellites and from the Moon has advanced optically printed sound reproduction to a point where it is strongly competitive with sound reproduction from magnetic tracks. The optical sound-reproduction system is now being marketed for single- and multiple-channel film projectors.

Metal-oxide silicon field-effect transistors have also been incorporated in high-fidelity stereo systems, in both amplifiers and FM tuner circuits.

3. Data-compaction techniques, adaptive telemetry systems, and digital communication links under development for meteorological and Applications Technol-

ogy Satellites should make possible significant improvements in monitoring aircraft performance and reducing turn-around time at air terminals. The improvements will be especially important for supersonic passenger planes, which will need to sample and transmit far greater quantities of data about their in-flight performance than present planes do.

4. The space program has made possible telemetered communications that are highly reliable in situations where the information rate is slow and the transmissions infrequent. There are obvious applications of this technological advance in civil communications: for instance, in telemetry from water gauges, metering of traffic flow, and burglary- and fire-alarm systems.

5. The Jet Propulsion Laboratory is developing a computer system that tests and repairs itself, automatically replacing faulty components when necessary. This system, known by the acronym STAR, for Self-Testing and Repairing, should eventually be of importance to telephone and teletype exchanges, both civilian and military.

6. A new maser refrigerant system of improved reliability, higher maser sensitivity, and much lower cost now brings masers within economic reach of far more manufacturers of communications apparatus than before. The low-noise maser amplifier is also a valuable improvement stemming from space-program needs. High-quality, low-cost masers will contribute to better telephone, telegraph, and television transmission via communications satellites.

7. Cassegrain antenna feeds devised for ground stations to improve communications with spacecraft at extreme ranges have been so successful that they are being planned for most of the international ground stations intended for the forthcoming worldwide system of communications by satellite. Propagation of radio-frequency energy over interplanetary distances has also stimulated the development of very low-noise receivers. In fact, worldwide communications capabilities have improved dramatically in the last few years as a direct result of the use of these space-developed techniques and equipment.

8. The success of integrated circuitry in communications and weather satellites has led one of the principal manufacturers of color television sets to use circuits of this type almost exclusively in its commercial products.

WEATHER

1. The United States now has in initial operation a meteorological satellite system, providing essentially global weather observations daily for central analysis and forecasts. NASA designs, procures, and launches the satellites; the Department of Commerce and the Environmental Science Services Administration operate and manage the system, and process and distribute the data it produces.

The meteorological satellite system also enables some 200 suitably equipped ground stations throughout the world to sample automatically the satellites' photographs of weather conditions in the vicinity of those various stations. This automatic picture-transmission system has become particularly popular with weather forecasters all over the Earth. In addition, several commercial television stations have acquired their own equipment for tapping the meteorological satellites' store of weather pictures. They display pertinent orbital pictures during their regular telecasts of Weather Bureau forecasts. According to the stations' reports, their audiences love this vivid Space Age improvement on traditional weather predictions.

2. An interesting and practical application of the NASA-developed system for obtaining photographs of local weather conditions from meteorological satellites as they pass overhead is being put into daily use at New York's John F. Kennedy International Airport. It has long been a requirement that pilots of aircraft on transoceanic flights be given a "significant weather chart" of their routes before takeoff. These charts indicate areas of frontal activity, cloudiness, clear air, and turbulence, give cloud heights, and locate jet streams. Now, in place of the previous charts, meteorologists at Kennedy Airport are providing pilots with mosaics of photographs obtained through the local Automatic Picture Transmission station from meteorological satellites. These photographs cover essentially the entire North Atlantic. The meteorologists annotate them by hand and then duplicate them in quantity; thus pilots are provided with the latest weather intelligence before heading across the ocean. The photo mosaics are marked to show anticipated movements of major frontal systems, so that a pilot will be able

to identify the features he sees in the photos by the time he reaches the area pictured. Fronts, centers of low pressure and high pressure, maximum winds, heights of cloud tops, and other crucial details are shown on the mosaics.

It is expected that this new system, as it is perfected, will eventually supplant entirely the former charts of significant weather information. The Weather Bureau will doubtless in time be able to provide photo mosaics of en-route flight conditions at each of its aviation forecasting installations located all the way from Guam eastward to the Atlantic coast of the United States, covering current weather conditions from the eastern shores of Asia to the western shores of Europe.

3. Sounding balloons for the Weather Bureau and meteorologists of the U.S. armed forces may be improved by adapting a curious new design called a "jimsphere." This design, developed by a NASA contractor, has a spiky surface instead of a smooth one. It has been found to be much more stable than ordinary sounding balloons with less erratic motion in strong winds.

4. Meteorologists are studying infrared photographs of the water-vapor portion of the infrared spectrum with the expectation of being able to determine the directions that storms move and the reasons why they dissipate. From these same photos, they hope to learn how to track jet streams precisely. If jet streams can be pinpointed continuously, airlines can save a considerable amount of flying time.

5. Orbital measurements of sea state by means of radar scatter have proved to be practicable. Global observations of sea state, which would be prohibitively expensive by any means except the use of Earth satellites, promise to fill one of the most important needs of wave forecasters. These forecasters cannot develop equations for wave development without adequate initial observations to go by, and observations aren't available over most of the globe at the present time. Orbiting spacecraft can provide them.

6. The daily availability of local cloud pictures from meteorological satellites equipped with the automatic picture-transmission system has given many foreign countries a capability for developing their own national meteorological systems at a cost they can afford. This benefits the United States not only by creating goodwill but by broadening the base of our international program in meteorology. This broader base of observational data is essential to the development of long-range weather forecasting and to evolving the technology of modifying weather to suit man's seasonal needs.

POWER SOURCES AND PUBLIC UTILITIES

1. Copper composites reinforced with tungsten fibers have proved promising for use as high-strength electrical conductors. The tungsten-reinforced copper composites have ratios of tensile strength to resistivity and density that are superior to those of commercially available electrical conductors.

2. It is now possible to evaluate proposed designs of brushless rotating electrical generators by means of computer programs. This eliminates the necessity for building prototypes of the generators for evaluation. The same computer programs have also supplied the necessary information for generator-design manuals that should prove invaluable to working engineers and engineering students.

3. By using ultrapure materials, a cobalt-iron alloy has been produced whose magnetic properties are better than those of any other known material for applications in the temperature range of 600 to 1000 degrees Centigrade. The alloy, with an iron content of 7–9½ percent, has a high Curie point, good maximum induction, and low electrical losses, making it suitable for high-temperature electrical apparatus. This development should be of significant value in lightweight electrical power systems, rotating machinery, and transformers, as well as in computer memory devices utilizing magnetic alloys.

4. Cermet insulators consisting of a layer of alumina sandwiched between two layers of niobium and formed at high temperature and pressure in an autoclave have been found to combine desirable electrical-resistance insulating properties with good thermal conductivity.

5. A battery has been designed and successfully tested for use in a high-temperature environment. This cell, with a magnesium anode, an electrolyte of lithium chloride and potassium chloride, and a mixture of copper and cuprous oxides for its cathode, operated in temperatures ranging from 670 to 1200 degrees

Fahrenheit with a consistent, though not necessarily optimal, energy density of 28-watt hours per pound.

6. The space program has contributed to the development of lightweight, high-capacity batteries capable of many charge-discharge cycles. These batteries are making possible the creation of many additional cordless appliances.

7. A new additive for heat-sterilizable silver-zinc batteries gives promise of extending not only the shelf life of sealed batteries of this type but their useful life as well.

8. The nuclear-resistant qualities of the magnetic logic computer developed for spacecraft could be put to use in controlling atomic power stations on the ground. Also, techniques created to meet NASA needs for measuring nuclear and atomic properties will ultimately be utilized in commercial power-generating packages.

9. Radioactive power sources developed for space vehicles that are unable to obtain necessary energy from the Sun can be used to operate remote weather stations, buoys, and, particularly, monitoring stations under the sea. A small radioisotope power-generation system created for use on the Moon is capable of providing nearly two watts of electrical power per pound.

10. Advances in the technology of refractory, alkali-metal, fast nuclear reactors for space-program applications may hasten the development of breeder reactors for commercial power generation. Reactors of this sort would permit increasing steam temperature to approximately 1200 degrees Fahrenheit, which in turn could increase power-plant cycle efficiency to 40 or 50 percent.

11. An important developmental program involves the use of thermionic diodes to generate electrical power aboard spacecraft. A significant possible commercial application of this technology would be in nuclear power plants, where banks of thermionic diodes could be used along with conventional steam-powered generators to convert waste heat to useful power. By this means, the efficiency of nuclear power plants might be increased by at least 10 percent and their fuel requirements reduced accordingly.

12. A self-oscillating inverter for changing direct current to alternating current in low input voltages is now being utilized commercially in a lightweight, portable, airport-runway lighting system operated by batteries. A large manufacturer of semiconductors has also recommended the same design for a number of other special applications.

13. Aiming a laser beam at a remote photovoltaic cell provides a means of supplying a sustained level of electrical power at a location that cannot be served by conventional cables and conductors. At the remote location, the light energy of the beam is converted to electricity through the photovoltaic cell. In some applications this system is superior to cables and microwave links, which consume more power.

14. An acidified solution of didymium nitrate was found to increase the ampere-hour capacity of nickel-cadmium cells without affecting their voltage outputs. A supplier of rare-earth elements has reported that it intends to provide this NASA-developed additive for manufacturers of batteries and power cells.

15. A solid-state ampere-hour integrator has been devised for testing batteries. It eliminates the effect of a transformer's magnetizing current, and thus provides an output virtually free of error, even when measuring small currents. This device is being used to evaluate the performance of electrochemical batteries for spacecraft, but it would be valuable wherever one needs to determine battery performance. It represents a significant laboratory tool for the advancement of battery technology.

16. Cadmium-cadmium coulometers have been shown to be effective in controlling the charging of nickel-cadmium spacecraft batteries. The use of this device in the battery control system reduces the rate of overcharging. Commercially, it has special usefulness wherever a charge must be obtained in a very short time, as in aircraft systems.

17. In batteries with silver electrodes, such as the silver-zinc cells now being used in prototype electric automobiles, the migration of soluble silver tends to cause internal short circuits. Consequently, battery life is shortened and reliability is questionable. A process has now been developed for electrodepositing inorganic materials on silver electrodes. This type of deposit can essentially halt silver migration and extend battery life by two to five years.

18. The unique variable-field motor, developed at Goddard Space Flight Center as an outgrowth of work with brushless motors, has wide versatility and potential application, primarily for DC motors, in the high-power area. Its uniqueness stems primarily from a particular feature of construction, which allows both the field winding and armature winding to remain stationary while a magnetically "soft" iron rotor turns.

The motor can be used wherever high efficiency is needed and where arcing and brush wear are undesirable, as in munitions plants, mines, hospitals, aircraft, and mills. The variable-field motor could also be readily designed in a linear configuration as a means of propelling rapid transit.

TRANSPORTATION AND COMMERCE

1. Orbital photography in color appears to be a quick and dependable means of checking the completeness of hydrographic charts in poorly mapped areas and of detecting unmapped shoals. Color photos taken of the mouth of the Colorado River from Gemini spacecraft confirmed the well-known fact that there is a general correlation between water depth and photograph color. Orbital photos of the mouths of several of the world's largest rivers clearly show the distribution of sediment-laden fresh water after it enters the ocean. The areas involved are far too large to be photographed with comparable efficiency from an airplane. Satellites can do the job easily.

2. Photos taken by operational weather satellites are now the basis of charts, routinely prepared during the winter and spring, depicting the distribution and types of ice in the Great Lakes and the St. Lawrence Seaway. These charts are of importance in forecasting the seasonal breakup of ice and in determining safe routes for vessels in those busy waters. Satellite photos have also helped select the best routes for icebreakers to take and ships to follow in transporting supplies to the Antarctic. The photos are especially important in that remote region, which almost totally lacks other sources of weather information.

It has also been found that a qualified photo interpreter can distinguish between clouds, ice, and snow. This ability is being put to use experimentally in determining snow distribution from a study of orbital photos. Snow distribution is significant in forecasting water supply in certain areas, particularly in the mountain regions of western United States.

3. Improvements in the range and doppler velocity sensor used by Surveyor spacecraft during final descent and soft landing on the Moon have made the sensor a more accurate and reliable device than it was before, and enhanced its value for future use in supersonic or hypersonic aircraft.

4. In last year's report, it was noted that knowledge gained in generating and handling extremely large bulk quantities of liquid hydrogen, oxygen, and nitrogen for the space program had led to cost reductions that should open new commercial markets for these products. Liquid nitrogen is now being used in large quantities to preserve bulk shipments of fresh fruits and vegetables.

5. Thermal-scale modeling developed for spacecraft could be adapted to improving air-conditioning systems for buildings and for automobiles, buses, trains, and airplanes.

6. The critical fact that airplane tires can and do hydroplane on water-covered runways was discovered in the course of investigation by the Langley Research Center into the performance of tires on wet surfaces. This disclosure had obvious implications for automobile safety, and the research was extended in cooperation with the Department of Commerce, the Bureau of Public Highways, and the General Services Administration with the intent of defining important considerations of wet-road driving safety. The results of this work have demonstrated the crucial influences of speed, tire pressure, water depth, road texture and curvature, tire-tread patterns and wear, combinations of brake-locked wheels, and so forth, on the hazards of highway hydroplaning. They have formed the basis for an educational film, called "Automobile Tire Hydroplaning—What Happens!" They have also captured the attention of highway-safety officials at all levels of government and have inspired broad, new efforts to improve tires, braking systems, and road surfaces.

7. A method of evaluating rough airbase runways for correction has substantially reduced costs, increased the effectiveness of repairs, and lessened the time needed to keep the runways out of use during repairs. The same method might be applied to evaluating and monitoring the condition of highway surfaces.

HEALTH AND MEDICINE

The practical advantages of space research and technology are especially impressive and heartening in the improvement of medicine and public-health services.

1. A six-patient physiological monitoring system, which evolved from Mercury and Gemini technology, has been installed in a St. Louis hospital and is being marketed commercially. The system includes bedside consoles and oscilloscopes, two multiplexers used to display several traces simultaneously on each scope, a strip-chart recorder, a magnetic-drum recorder, and an audio alarm.

2. An air curtain developed to keep spacecraft parts free of dust during assembly is now being used by the Food and Drug Administration in testing antibiotics. The air curtain insulates the test bench and substantially reduces the number of test failures that can be attributed to dust-borne micro-organisms.

3. Aluminized plastic only half a thousandth of an inch thick, created initially for superinsulation in space, is now being sold commercially for use in blankets for emergency rescue and similar purposes. The material has unique heat-reflecting properties and surprising strength despite its thinness. It is made into full-size blankets that can be folded into pocket-size packages. The blankets can also serve as stretchers, windbreaks, or water containers.

4. A switch operated simply by eye movements was developed for NASA and has now been adapted for use in a motorized wheelchair. The sight switch, properly relayed, enables a paraplegic to control the wheel chair without moving his body or limbs. The same switch could be adapted for use as a mechanical pageturner or to enable a patient to control lights, thermostat, radio, or television set without moving.

5. A six-legged walking vehicle devised as a remotely controlled instrument carrier for automated exploration of the Moon has been adapted for use as a walking chair for limbless or otherwise crippled individuals. It can be controlled either by a chin strap or by hand and it can negotiate terrain, such as curbs and beaches, that would be impossible for an ordinary wheelchair.

6. A telemetry unit designed for cardiac monitoring of astronauts has been modified for marketing to hospitals for use in intensive care units.

7. Components of currently available pressure suits for space and stratospheric flight have been used to provide external blood-pumping assistance to patients with cardiovascular defects. Further development of such artificial, outside means of stimulating human circulation seems certain to derive from pressure-control techniques now becoming available in the space program.

8. NASA studies of ways to avoid the potentially degenerative physical effects of space flight have included the development of pressure cuffs and special exercising devices and techniques that can be applied to the care of bed patients forced to remain immobile for long periods.

9. Largely as a result of space-program requirements for radiometers in satellites, for horizon sensors, and for a variety of detection systems based on sensing heat, infrared equipment has been devised that detects "hot spots" in human bodies, suggesting the presence of malignancies or other pathological conditions.

10. Techniques for automatically recording the blood pressure of astronauts and pilots have been adapted to commercial use in a portable automatic blood-pressure recorder. It gives consistent results even when used by untrained persons, and thus frees trained nurses for other duties.

11. A special dialyzing apparatus devised for use in molecular biology has been modified to control the exchange of fluids and salt more efficiently in artificial kidneys.

12. The laminar-flow clean-room technique developed for controlling contaminants has been applied to at least one surgical operating room with marked success. The use of this space-program technology is expanding. Drug manufacturers are now being urged by their industry organizations to adopt the laminar-flow clean-room technique in the preparation of pharmaceuticals.

13. New fundamental knowledge of sterilization and antisepsis has been obtained by directly exposing unprotected Earth microorganisms to the environment of space and recovering them. For the first time, it is possible to measure the respective sterilizing effects of high vacuum, cosmic rays, ultraviolet rays, X-rays, and temperature extremes in relation to specific lengths of exposure to those various conditions.

14. Research being conducted on various aspects of the auditory system has led to the designing of an analyzer of frequency spectra for electroencephalography. This analyzer can compute and display a spectrum while the data are being accumulated, and thus provide the time perspective that is a key factor in interpreting EEG's. Besides its use as a research tool, this new instrument may prove useful in such diverse applications as monitoring the vigilance of an astronaut or a pilot, providing a compact summary of the EEG of a hospitalized patient, or monitoring anesthesia levels during surgery.

15. Gas chromatography is being used for the first time in tandem with mass spectrometry for the purpose of detecting extraterrestrial life. This instrument team also provides a rigorous means of identifying human blood components related to disease.

16. The curious discovery that a turtle's eyes are unaffected by ultraviolet radiation sufficiently intense to blind a human being should be of use in research dealing with the transplant of human corneas and other tissues, and also in research investigating means for protecting us against radiation.

17. It is well known that living cells and tissues can be preserved very satisfactorily by freezing. But always before, when they were thawed and maintained in a normal oxygen environment, they died. An important recent advance in knowledge derived from these experiments is the revelation that when frozen cells and tissues are thawed and maintained in an environment deprived of oxygen, they survive and grow without damage.

18. Further studies of the effects of simulated weightlessness on bones have produced some specifics. Immobilized animals, for example, have shown not only a 27-percent increase in calcium loss—an effect attributed to a deficiency in Vitamin C—but, more importantly, a reduction of 37 percent in their capacity to make up this calcium loss. Research of this type in fundamental biochemistry is revealing information that will help us to maintain better conditions of health, particularly bone, in the general population as well as manned efforts in space. Such research is helping us to resolve some of the more difficult problems in the general field of bone disease, its understanding, and its treatment.

19. The automated system for conducting urinalysis of primates during biosatellite missions and telemetering the periodic analyses for recording could be easily adapted to broader purposes. It could determine a large variety of either urinary or blood constituents. It would be practical to use the automated system in experimental animal tests that are part of pharmacologic studies of drugs. It would be particularly useful for routine hospital procedures such as the functioning of an artifical kidney. The automated system could substantially lower costs and increase the speed and efficiency of clinical testing.

20. Components such as the back-pressure regulator developed for our biosatellite program could be applied to improving life-support systems for use in remote areas of the Earth, especially in underwater exploration.

21. Preliminary experiments indicate that it might be possible to apply to the measurement of blood viscosity the parallel-plate viscometer used in studies of solid-propellant slurries. Special advantages are that only a tiny sample is needed, and that it can be measured within a few seconds of extraction. Blood-stabilizing agents, which could interfere with a true viscosity reading, would not be necessary.

22. The flow of blood in capillaries can be tracked optically by a device developed for observing test vibration of spacecraft on a shake table. Measuring blood flow is a valuable tool in determining the response of the body's fluid-transport mechanisms to drug injection.

23. Computer techniques for enhancing television pictures derived from Ranger, Mariner, and Surveyor missions are applicable to several medical areas. These include getting more useful information from X-ray photos, from microscopic analyses of chromosomes, and from electronmicroscope surveys of nerve tissue.

24. Techniques for automatically correlating and cross-correlating data being processed have been brought to a high degree of proficiency in space communications and other areas of the space program. Similar methods are now being employed in other fields, such as that of medical electronics, where they are applied to the analysis of brain waves.

25. Work is under way on a flexible suit that will act as a biological barrier between the wearer and his outside environment. The suit is primarily intended for the purpose of making adjustments and repairs on a sterile spacecraft. It offers important potential for biomedical applications, however. It may provide a means of conducting completely sterile surgery, as is desired for organ trans-

plants, or of protecting researchers investigating particularly dangerous diseases.

26. Development of a laminar-flow clean room that can be completely sterilized by dry heat should find important biomedical and medical applications. The method not only would provide a totally sterile operating room for a surgeon before anyone entered it but would keep it 100 times cleaner biologically during operations than the average surgery can be kept today. The same technique applied to a hospital recovery room could substantially reduce the possibility of post-operative infection.

27. NASA-supported research on the physiological and psychological effects of artificial changes in the length of the day, owing to the time distortions produced by transcontinental and intercontinental flights, has already affected medical advice given to airline passengers. It may also help to solve the difficulties of industrial medicine in advising how best to distribute working hours per day.

28. An electromagnetic-flow meter originally developed for the missile industry is now being used at the University of California, Los Angeles, to diagnose erratic heart action that otherwise might be difficult to detect.

29. An interesting aspect of space medicine is that it not only is constantly seeking new ways of measuring standard parameters but it explores variables that are largely ignored in conventional clinical medicine. Space medicine has found, for instance, that there is particular diagnostic promise in measuring the pulse-wave velocity—the acoustic properties—of flowing blood.

30. Accelerometers developed to study acceleration effects in space travel are now being used, variously, to study the protective value of football helmets, the tremor pattern in patients afflicted with Parkinson's disease, and the ways in which injuries are produced in automobile accidents.

31. In space research, the use of slowly rotating rooms helps determine an individual's perception of motion and his illusions regarding his physical position. These revolving rooms have also contributed to a better understanding of the basic function of the vestibular organ. Improved knowledge and treatment of motion sickness and the development of superior anti-emetic drugs should evolve from this research.

32. New devices stemming from the space program that assess the efficiency of human performance are now commercially available. A response-analysis tester presents the subject with a choice of reactions to a given situation, and a logical-inference tester then measures the subject's reasoning, memory, and decision making in response. These devices can be used to detect loss of efficiency due to anxiety, fatigue, sickness, or age.

33. As a means of measuring human metabolism by determining the body's heat loss through evaporation, a space-instrument company has constructed a bed that is an extremely sensitive device for recording its occupant's hydraulic balance. The bed has been used to determine a patient's water loss in burns, the degree of water loading in heart failure, and the body's fluid balances in diabetes, hemodialysis, and surgery.

34. New techniques developed to check the condition of rockets have resulted in radiation dosimeters so small that they can be mounted on the point of a hypodermic needle for the purpose of determining radiation dosage in local tissue.

35. Another fascinating example of effective miniaturization for medical purposes is the microlamp. It is the outcome of research in illuminating panel dials essential to missile control. The microlamp is so tiny that it can pass through the eye of an ordinary needle, yet it gives a brilliant light. This promises to be valuable for internal diagnoses, such as viewing the interior of the stomach, and possibly for surgery.

36. NASA has sponsored a number of industrial contracts that have produced marked advances in the quality and use of implanted sensors. For example, implantable oximeters now make it possible to monitor breathing with greater efficiency during surgery. Intra-arterial manometers continuously record blood pressure during major surgery. Radio pills are effective as sensors and transmitters of temperature, blood pressure, acidity, and alkalinity. And implanted, body-powered stimulators work effectively both as heart pacers and as artificial means of forcing muscles to contract.

37. Development of oxygen chambers with atmospheric pressures higher or lower than normal has contributed to the possibility of using controlled environmental pressure and gaseous composition to treat pulmonary emphysema and comparable diseases, to care for premature babies, and to treat decompression sickness.

38. A concept has recently been advanced for using a self-winding watch movement to power a transmitter for physiological telemetry. The complete device will be about the size of a watch and may be strapped to a patient's arm or leg. His motions will keep the watch wound and the transmitter functioning. The sensor, whose lifetime would be virtually unlimited, could be used to monitor temperature, blood pressure, or the body's acidity or alkalinity.

EARTH RESOURCES

Growing problems of water and food supply, mineral and fuel sources, water and air pollution, and traffic congestion plague the people of the world with increasing insistence. Some of these problems are predicted to become acute within the next few years as the Earth becomes more densely populated. Although space operations will not in themselves provide any solutions, they will give key information on which effective action can be based.

1. The distribution of rainfall and the subsequent storm runoff in drainage basins of small to moderate size are of considerable scientific and economic importance in water management, especially in arid regions where thunderstorms are the major source of precipitation. A photograph taken from Gemini IV clearly shows the track of one such storm in West Texas, and demonstrates the potential usefulness of remote-sensing techniques to this problem. Time-sequence measurements are naturally of prime value in studies of rainfall distribution and runoff, and only the orbital approach offers the special advantage of both synoptic and frequently repeated coverage of large regions.

2. Investigations are being made of the ability to use remote sensors in aircraft and spacecraft to identify and study areas of ground-water discharge into bodies of surface water. It is important to delineate those areas, for they may be underlain with productive aquifers capable of supplying large amounts of water consumption. The U.S. Geological Survey has used infrared imagery successfully to locate and delineate areas of ground-water discharge to the ocean from the island of Hawaii, and also to indicate ground-water discharge into a small river.

3. It has been demonstrated that the degree of sedimentation in reservoirs can be determined photogrammetically from the air with the use of film and filter combinations that provide good water transparency.

4. Studies currently being conducted in specific areas of known water pollution have shown that orbital observations can probably be used to locate pollution and monitor its movement in large lakes and estuaries, repeatedly and on a very broad scale. Infrared imagery shows great promise in studies of mixing processes where waters of different temperatures come together, as in estuaries and at river mouths.

5. Analyses of a number of Gemini color photos reveal that even simple camera systems in orbiting spacecraft are able to provide synoptic data on the location and relative size of the Earth's settlements from the largest down to those of the size, say, of Tucson, Arizona. Improved resolutions that we can anticipate should make it possible to locate and identify all but the smallest clusters. In addition, it should be feasible to analyze the complex internal structure of the larger units of population. This might include gross land use, and even specific, detailed land uses in places where sensor returns are most accurate. Information relating to the internal structure of large urban areas is highly useful in urban and regional planning as well as in geographic research.

Aircraft overflights using both infrared color photography and radar imagery have produced clear patterns of associated rural and urban lands, and have also revealed the influence of TVA and other resource-development programs on the areas affected.

6. Geologic maps are being corrected and made more useful both scientifically and commercially as a direct result of color photographs of the Earth taken from Gemini spacecraft. A total of 1,400 pictures of land and near-shore ocean areas were snapped in the course of a synoptic terrain photography experiment conducted by Gemini astronauts. The color photos revealed many geologic structures and rock units in northern Baja, California, that hadn't been mapped before. They disclosed a major volcanic field of Quaternary age in Chihuahua, Mexico, that didn't appear on the latest geologic map of North America, published in 1965. The photographs helped correct inaccuracies and supply information missing from the best available topographic maps of Saudi Arabia. Most importantly, perhaps, the Gemini pictures of Southwest Africa revealed a large number of geologic structures in a major mining district that had not been indicated in the most up-to-date geologic map of that area, and showed the regional distribution of sand dunes in the Namib Desert. This may not appear to be a significant

achievement, but it happens that there is an important diamond field in the Namib Desert, and the diamonds occur in alluvium between the sand dunes. Therefore, locating the dunes accurately is a matter of importance.

In addition to the returns noted above, Gemini color photographs were also instrumental in locating a new potential ore deposit in New Mexico.

Gemini photographs have covered (a) new areas not previously photographed, (b) have extended or improved our coverage of areas previously photographed, (c) have demonstrated the value of infrared color film in photography from spacecraft altitudes, and (d) have shown the effectiveness of moderately long focal lengths.

7. Radar imagery readily recognizes lakes, rivers, oceans, and moisture in soils. Since fine-grained materials, such as sand and clay, retain water better than coarse-grained materials, radar can thus be useful in mapping groundwater distribution. Radar also has the unique ability to penetrate vegetation and reveal the finer topographic details, which are not evident in photographic images. Radar data from orbiting spacecraft thus have great potential for aiding mineral exploration, since many ore deposits can be located through identifying adjacent rock structures—more readily in some parts of the world than in others.

8. An analytical technique has been devised for determining the mineralogical and chemical composition of rock surface from analyses of their reflectivity in the 8-to-13-micron wavelength region. The bulk composition of the rock surface can be determined by matching the incoming spectra with standard curves in the memory of a computer. Evaluation of spectral rates up to seven per second appears feasible by this method, thus permitting geologic mapping from spacecraft as well as from aircraft and moving ground vehicles.

9. Infrared imagery has revealed hot surface areas in Yellowstone National Park that hid natural hot water and steam. This suggests that sources of geothermal power, such as those in Iceland, can be detected and monitored best from space. The value of geothermal power sources may someday rank with that of oil and gas deposits.

10. Existing instrumentation is capable of remotely sensing vapor concentrations as small as a few parts per billion and has many potential geologic applications. For example, oil-field brine shows high concentrations of iodine, and iodine is highly volatile. An instrument that could detect iodine or methane vapor in very small amounts might lead to the discovery of oil fields of the sort that have surface seepage.

11. Magnetometer observations from space should provide three-dimensional geologic information on the structure of the Earth's crust and the forces that affect it at the juncture between crust and underlying mantle. There is evidence of a correspondence between deep-seated magnetic anomalies and major mineral districts. Airborne magnetic maps are remarkably effective in delineating many types of intrusive and extrusive rocks, even when they are buried beneath deep overburden. Most aeromagnetic surveys up to now have been limited to land areas. Spacecraft will provide the most economical means of extending this search over ocean areas.

12. Although it is unlikely that marine mammals and schools of fish will be viewed directly from orbital altitudes in the near future, we have already found that concentrations of schools of certain fish show up as narrow temperature zones in readings of an airborne infrared thermometer. Spacecraft with IR or microwave temperature-sensing instruments can extend this kind of work to worldwide coverage. Moreover, infrared color photography can be used to emphasize plankton blooms, thus revealing areas where fish feed.

FOOD AND AGRICULTURE

1. Infrared photographs of the Gulf Stream taken from the meteorological satellite Nimbus II show promise of being of tremendous value to the commercial fishing industry as well as to weather forecasters. Because the Gulf Stream is about 10 degrees warmer than surrounding waters, it shows up clearly in the infrared spectrum. NASA scientists and Navy oceanographers were able to locate its northern boundary near Cape Hatteras very distinctly by studying infrared photos from Nimbus II. Fishing experts say that they would know consistently where to find several species of fish if they could accurately plot the daily wanderings of the Gulf Stream. A better understanding of the Gulf Stream's shape and almost constantly shifting course would also be of great importance to weather prediction.

The Gulf Stream covers a huge area, and it would take ships and planes at least 10 days to map it as thoroughly and accurately as Nimbus can do in a few minutes. Besides, by the time the ships and planes had completed the job, the Gulf Stream would no longer be where they had located it.

2. Ordinary color photography from orbiting spacecraft has also demonstrated its potential value to commercial fishing. Pictures taken on various Gemini flights gave abundant detail on the distribution of currents and sediment in the shrimp-fishing areas near shore in the Gulf of Mexico. Other color photographs from Gemini craft revealed the distribution of smooth patches of water, which in turn may indicate concentrations of organic matter on which fish feed.

3. Color photos taken from orbiting spacecraft of various arid regions, where virtually no soil mapping has been done, should be of exceptional value in desert reclamation projects. Gemini photos of the American Southwest, Mexico, North Africa, and Saudi Arabia distinctly reveal the regional distribution of soil types.

4. Continuing refinement of our methods of simulating sunlight will lead to greatly improved testing of agricultural plant life. The ability to provide artificially any desired length of daylight, flux density of solar energy, and angle of incidence will enable us to closely approximate actual growing conditions in the fields and orchards of various Earth latitudes at all times of the year.

5. Current research is revealing that the use of imagery in several wavelengths from aircraft and orbiting spacecraft can determine crop species and variety; relative size and maturity of crops; types of soil, moisture content, and relative amounts of soil and vegetation observed; and the geometric configurations of crops. Multispectral imagery also depicts vegetation zones as they vary with elevation, reveals trace-burn patterns of previous forest fires, and delineates timber lines. Of particular significance is the fact that using several wavelength bands of the electromagnetic spectrum provides a much greater degree of reliability than the use of single bands.

Infrared imagery shows up dead and diseased trees more clearly than standard color photography does and reveals the contrast between well-drained and poorly-drained areas. The rapid detection of infected trees should speed up the application of control measures, such as spraying, and help reduce the spread of infestations.

SCIENCE

1. New coatings have been developed for silicon solar cells that cause them to respond to a wider spectrum of light than ever before and at the same time resist better the deteriorative effects of radiation. These coatings thus enable the solar cells to produce electric power under a greater variety of conditions than before.

2. Ultraviolet spectrograms of stars were obtained on the late Gemini missions. These have been compared with ultraviolet spectrograms of the Sun obtained on rocket flights, and the results tell us more than we knew previously about the ultraviolet-energy output of hot stars, such as Sirius. By use of the spectrograms, more than a hundred stars have now been given rough ultraviolet classifications, and more extensive information has been acquired on a few bright stars.

3. Research at the Jet Propulsion Laboratory on the statistical theory of the atom may be applied to explaining and predicting the behavior of matter under extreme pressure—as, for instance, the center of the Earth or in a nuclear explosion.

4. A miniature seismometer created for use on Ranger spacecraft and intended for monitoring extremely small lunarquakes is now in use along the well-known San Andreas fault on the West Coast of the United States, the location of California's severest earthquakes. A better understanding of the general phenomenon of earthquakes is expected to result from the readings of the miniature seismometers. Infrared imagery in the 8-to-13-micron band, obtained from aircraft overflights, is also being used to study the San Andreas fault. Scientists evaluating the infrared photos for the U.S. Geological Survey report that the fault trace is clearly shown throughout most of its 200-mile length by variations in soil-moisture characteristics, and by offset segments of ancient stream channels, landslide terrain, and numerous units of soil and Tertiary bedrock.

5. The ranging system in conjunction with Lunar Orbiter missions has resulted in a new intercontinental time sychronization to within ten microseconds. This makes possible geodetic and astronomical measurements of unprecedented accuracy.

6. The techniques used in the design, development, testing, and operation of automated vehicles for missions to the Moon and planets are directly applicable to the technology of underwater exploration and the sciences of oceanography and limnology (study of fresh waters).

7. The geodetic satellite Pageos has been successfully placed in Earth orbit to provide a single global reference for the precise interconnection of various mapping systems of the world. Pageos was constructed of an aluminum-coated plastic that inflated itself into a spherical satellite 100 feet in diameter after it had been inserted into a polar orbit at an altitude of 2600 miles. Through simultaneously photography of the Sun-reflecting Pageos against star backgrounds from Earth locations up to 2800 miles apart, 41 camera stations throughout the world are geometrically connected to form a global geodetic network. By means of this network, points on the Earth's surface can be located to within from 51 to 96 feet of their true positions as measured from the center of mass, or to within 30 feet of their true positions relative to other points on the surface.

8. Since many of the basic concepts of navigating on Earth are not adapted to personal use by roving explorers on the Moon, NASA is developing a miniature inertial-guidance navigation system for this purpose. Experimental work has already produced a device as small as a coffee cup, which uses less than 10 watts of power, weighs less than 10 pounds, and has a location accuracy to within less than a quarter of mile.

It is evident that the technology involved should open a wealth of possibilities for miniature navigation devices that can be used on small boats and aircraft, for Earth exploration, and in military field operations.

9. A simple system perfected for rapidly locating spacereentry vehicles that have sunk to the ocean floor is being widely applied by government agencies in recovering other underwater objects, ranging from experimental nosecones to wrecked ships. The system consists of a miniaturized, self-powered, rugged generator built into the object to be recovered, which radiates ultrasonic signals underwater for detection and a small hydrophone receiver, carried by recovery ships or Scuba divers.

10. Formulas being developed to express man's responses to perception of displacement, velocity, acceleration, and so forth, and to express the effectiveness of his control response, are making it easier to improve flight-vehicle displays, controls, and systems for augmenting pilot performance on increasingly difficult missions. These formulas are broadly applicable and can have an important impact on the evolution of improved manually controlled machines for industry, farming, mining, transportation, national defense, and public use.

11. During 1966, laser tracking systems have been perfected and are ready for operational use. These systems offer the possibility of improving tracking accuracy by one or two orders of magnitude. This, in turn, will enhance the value of satellite geodesy to the Earth sciences.

12. Improved definition of the Earth's gravitational field now enables one to investigate small variations in the orbital motion of satellites. First results have given refined information on how much the solid Earth is deformed by the attraction of Sun and Moon. Correct definition of these Earth tides will have an important bearing on understanding the strength of the Earth's interior. Better information about gravitational effects on the orbits of satellites has also made it possible to determine short variation in the air-drag behavior of satellites and, in consequence, changes of short duration in the atmosphere.

The most important practical result of more thorough knowledge of the Earth's field of gravity is that it allows one to determine orbits more accurately for the entire space program and—this is of economic significance—compute orbits of any given accuracy with a smaller amount of tracking data than was needed before.

13. Gemini astronauts, using a simple handheld Hasselblad camera and taking pictures on a "target of opportunity" basis, give a preview of what may be expected as the science and applications program progresses. The following are examples of specific results obtained directly from analysis of Gemini photographs:

a. A large ephemeral lake, resulting from a recent landslide and previously unknown, was discovered in the Andes Mountains of South America. Supsequent engineering analyses pointed out the instability of the slide and showed a potential flood danger to the local population.

b. An ore deposit in the Southwestern United States was located and later confirmed by a private mining company. The value of this type of photograph

can be substantiated in part by the large number of requests for them by mining and petroleum companies.

c. A photograph of northwestern Saudi Arabia showed an important geologic feature (large wrench fault) not previously known. Although the area had been covered by a photomosaic at 10 times the scale of the Gemini photograph, the fault was not apparent. Delineating the rocks into gross units, as was done in this analysis, can save much time and expense in planning geologic projects such as petroleum and mineral exploration.

d. Hydrographic charts of the ocean have been updated in a number of areas using Gemini photographs. For example, the existing chart of Rongelap Atoll in the Pacific's Marshall Islands was found to be in error. Gemini photographs have also demonstrated the applicability for cartographic purposes, in updating of maps of the Cape Kennedy area.

e. A photograph taken during the flight of Gemini V of the northern part of the Amadeus basin in Central Australia clearly delineates three structural provinces and an unusual number and variety of smaller features. A number of companies are now conducting geophysical surveys of the plains in the northern anticlinal province for the purpose of discovering and delineating structures having sufficient cover to retain hydrocarbons in the petroliferous sequence encountered in one of the structures. Seven partly- to completely-concealed prospects have now been defined in the area covered by the photograph.

EDUCATION AND WELFARE

1. An impressive development in the evolving field of management science is a computerized training system called Gremex. The system was developed within NASA to indoctrinate and train actual and potential R&D managers in decision making and management practices of the space agency.

Gremex is a training exercise that portrays typical management problems and required actions of an R&D project manager throughout the life cycle of a 30-month project in a simulated real-world environment. Participants in the Gremex exercise make decisions for each month of the project's lifetime and feed those decisions into a computer for analysis. The computer, utilizing information available to the manager, indicates the time, cost, and performance effects of decisions made and actions taken. By successive analyses and discussions, participants in the exercise learn cause and effect, and ways to improve their insights and skills as managers. A creation of the Goddard Space Flight Center, Gremex made its debut before an industrial audience in August 1966. Since then, many companies have expressed a desire to find out how it might be adapted to their needs. Interested inquiries have also come from the Department of Defense, and from the University of Southern California, which has requested a Gremex demonstration to decide whether or not to include Gremex as a subject in the new Management Laboratory of its Graduate School of Business.

2. Astronomy textbooks will soon contain striking new illustrations. For example, a photograph taken from Gemini IX shows the Earth's zodiacal light free of the airglow always present in ground photos. Previously, it has been necessary to portray zodiacal light in a drawing in order to differentiate it from airglow and city lights and indicate its true nature. In the Gemini photo, airglow appears as a thin layer, with the moonlit Earth below it.

New textbooks in preparation on Earth sciences are incorporating many color photographs taken on Gemini missions. These reveal synoptic features of the Earth, such as huge fault lines, much more clearly than black-and-white photos do.

3. The problems and solutions associated with spacecraft development make excellent educational material for several reasons. They are topical, exciting, and interesting to students, technically sophisticated, interdisciplinary, and intellectually challenging. They require system-level thinking and the solution of problems containing multiple variables. Many members of the Jet Propulsion Laboratory staff have been instrumental in injecting spacecraft technology into engineering education. The result has been not only the transfer of knowledge and techniques but also the opportunity for students to acquire a better perspective by becoming familiar with actual engineering practices.

SOCIAL AND POLITICAL

1. NASA's cooperative satellite and sounding-rocket programs with several foreign countries are not only contributing to more cordial relations with those countries but are of significant benefit to American industry. For instance, in the

past few years, NASA has furnished the launch vehicles (Scout rockets) for scientific satellites supplied by Canada, France, Great Britain, West Germany, Italy, and the European Space Research Organization. For this program, the foreign nations involved have purchased, and will continue to purchase, many thousands of electronic parts available to them only in the United States. In addition, they have contracted with U.S. firms for major subassemblies (mostly electronic), ground checkout equipment, certain unique tests, and in many cases consultant services. In this cooperative venture, which is still going on, NASA has trained many groups of foreign scientists and engineers. The processes of training and consultation have inevitably brought about better understanding among the people concerned, technically, culturally, socially, and politically.

Other foreign satellite programs under way will result in the purchase of U.S. launch vehicles and launch services. Current plans of the European Space Research Organization (ESRO) call for buying three Delta launch vehicles for satellites that ESRO is building. In addition, U.S. firms are manufacturing parts and subsystems for those satellites.

NASA's cooperative sounding-rocket programs, too, help create both international goodwill and more business for American concerns. At present, there are cooperative programs with Canada, Norway, Great Britain, Sweden, Spain, West Germany, India, and Pakistan on major sounding-rocket programs. The financial benefits to the United States in these programs are not so large as those of the satellite programs, since the costs are lower, but the enhanced cordiality and mutual understanding growing out of the programs, especially in developing countries, is perhaps of even greater importance.

2. Research dealing with hydrogen-fixing bacteria for use in bioregenerative life-support systems for space journeys has revealed that these organisms are adequately nutritional to be used for important purposes outside the space program. Methods for cultivating the hydrogen-fixing bacteria on a massive scale are being devised for possible production of dietary supplements especially for cases of protein starvation. The supplements could prove to be of great value in countries where populations are deprived of a nutritionally adequate food supply.

3. The highly refined and sensitive computer programs and techniques that determine precise orbital positions and planetary distances could be applied to analyzing data from any source. These programs and methods could be used in medical diagnosis, prognosis, and treatment; in weather prediction and control; in limiting the spread of electrical power-system failures; in detecting conditions that indicate impending epidemics; and in providing early warning of harmful secondary biological effects from the area use of insecticides.

4. A continuing problem of society has been how best to organize huge masses of men, information, and materials for the accomplishment of socially desirable objectives. Space exploration represents, outside of the military structure, the largest known effort to organize scientific and technological personnel. This unique experience in combining the efforts of the academic, industrial, and scientific communities has consequences in the future for the accomplishment of national goals in many fields.

CONCLUSION

This concludes the latest annual summary of the practical advantages being derived from the nation's huge investment in space science, exploration, and applications. The benefits that this selected group represents are complemented by an active NASA program for specific transfer of items of technology to other elements of the economy.

The value of these examples, that have been presented here in the context of the testimony before this committee, is to give confidence in the existence of the much greater but less visible channel from the space program to the general economy. This channel consists of the other methods of transfer, such as stimulation by our programs in industry to put more of their own effort into developing new and improved products. Other means are by cross-utilization of personnel in both space and industrial areas; by publication of innovations in the professional literature; and by generally speeding the transfer of scientific and technological discovery into the educational process.

This transfer to the industrial, economic, educational, and management base makes the space program an increasingly vital and integral part of our everyday lives.